R669.1361 I71

STACKS

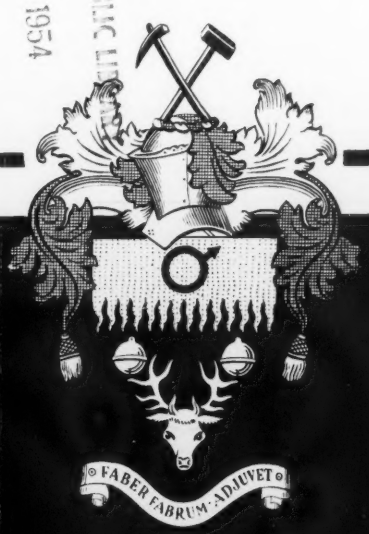
DECEMBER, 1954

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON S W I

LOS ANGELES PUBLIC LIBRARY

DEC 31 1954



Established 1869 · Incorporated by Royal Charter 189

VOL. 178 PART 4

Principal Contents

Convection and the Heating of Scrap
by L. F. Daws and R. D. Collins

Thermodynamic Calculation of Slag Equilibria
by K. Grjotheim

Transformation $\alpha \rightarrow \gamma$ in High-Purity Iron...*by P. R. Pallister*

Graphitization of Steel at Subcritical Temperatures
by R. H. Hickley and A. G. Quarrell

Slag/Metal Sulphur Distribution Reaction
by J. Taylor and J. J. Stobo

High-Temperature Water Cooling
by F. J. Feltoe and P. M. Moreton

Firing of Tilting Furnaces . *by W. Jackson*

Absorptiometric Determination of Molybdenum

Discussion on Papers

Letter to the Editor

News and Abstracts

A full list of Contents is given on the Title Page (see page 57, Advertisement Section)

This IS economy...

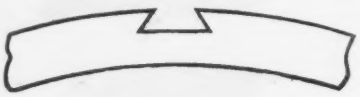
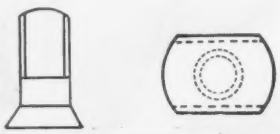
FERODO Friction Linings reduce renewals...

FEROLOK cuts renewal time

The manufacturers of tough, long lasting Ferodo Friction Linings help you to cut your maintenance costs and time—even more—with Ferolok, a unique, four-operation method of fitting industrial friction linings.

With Ferolok there is no need to remove brake shoes or other adjacent parts . . . with Ferolok, linings have no rivet holes, so adding to their working area—*and* working life.

This is FEROLOK, Ferodo's new time and money saving system:—

	The Ferodo Lining is supplied radiused and grooved.
	FEROLOK "keepers" fit firmly into the grooves. Keepers are made in sizes suitable for linings $\frac{1}{2}$" thick and upwards.
	FEROLOK bolts hold the keepers securely in the grooves and the dovetail action keeps the lining securely fastened to the band.
	When the bolts are loosened, it simply slides into position (as shown). The nuts are then tightened and the job is done.

To reline:—Slacken off the bolts. Slide off old lining. Slide on new lining. Retighten bolts.

1 • 2 • 3 • 4 —and the machine's back in service!

Send now for further details of FEROLOK, the new relining method for both internal expanding and external contracting brakes.

FERODO LIMITED

CHAPEL-EN-LE-FRITH

A Member of the Turner & Newall Organisation

WELLMAN

Re-Heating and Heat Treatment Furnaces for the Metallurgical Industries

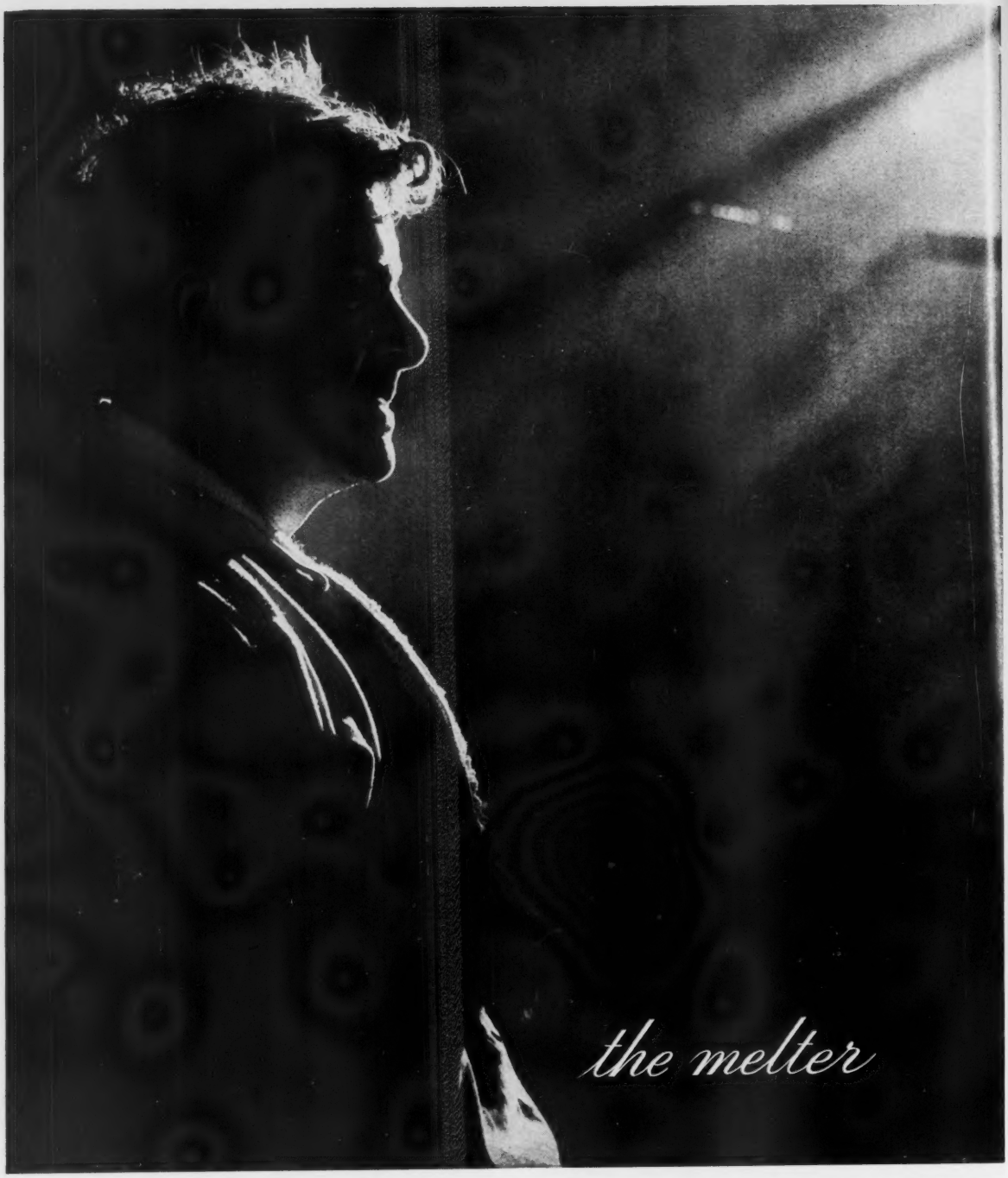
We design and construct Re-Heating and Heat Treatment Furnaces of many types for both ferrous and non-ferrous trades ranging from small units dealing with castings of a few pounds each up to the largest Bogie Heat Treatment Furnaces handling single pieces of 100-tons and upwards.

With the increased demands for precision and for constant quality, automatic control of furnace conditions is recognised as essential and this subject has received special attention in our engineering and research departments where every aspect of heating technology is studied.

We are also makers of the mechanical equipment required in conjunction with furnace plant, and are therefore in a unique position to design and construct complete installations incorporating the most recent advances in heat treatment and mechanical handling.

An installation of Wellman Oil-fired Furnaces for Annealing Brass and Copper Sheets.

THE WELLMAN SMITH OWEN ENGINEERING CORPN. LTD.
PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, SOUTH STAFFS.



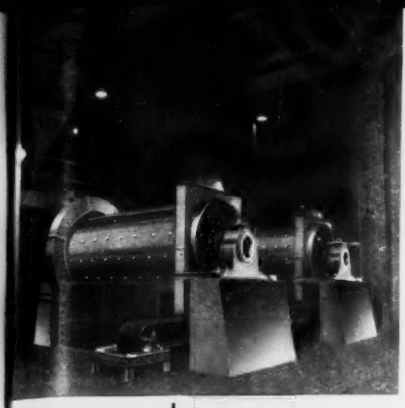
BROWN BAYLEY STEELS LIMITED

TRADE BROWN BAYLEY'S MARK SHEFFIELD 9

TELEGRAMS: BAYLEY SHEFFIELD 9 • TELEPHONE: SHEFFIELD 41031

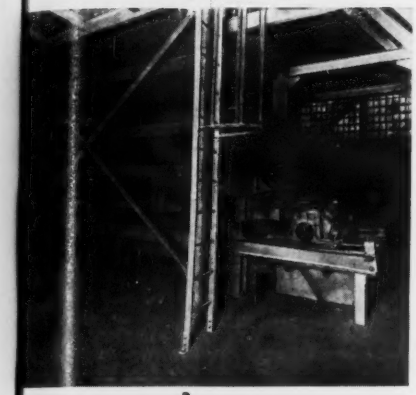
Newells

STEELWORKS PLANT FOR CRUSHING, HANDLING, MIXING AND GRADING RAW MATERIALS

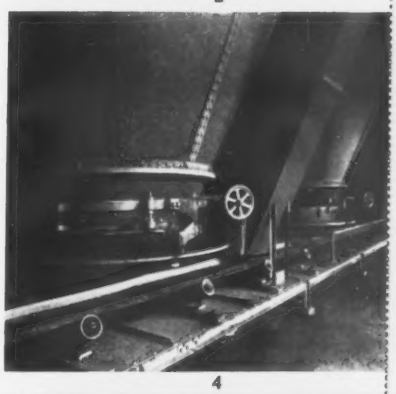


1

2

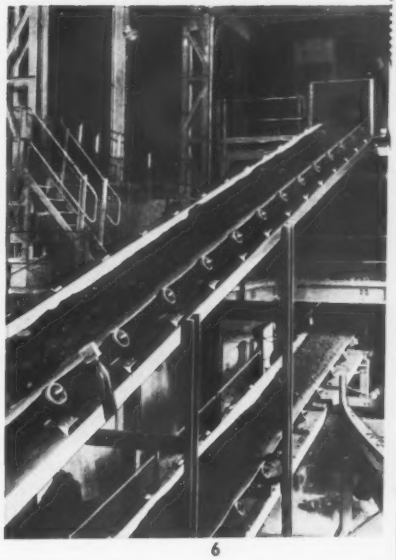


3



4

5



6

1 Rod Mills for fine crushing Coke Breeze for Sinter

2 Combined Rotary Drum and Paddle Mixers for Mixing Ore fines and Water for Sinter

3 All-Steel Apron Feeders for Iron Ore fines and Ferrous Sludge

4 Rotary Feeder Tables for Materials for Sinter

5 Iron Ore and Limestone Crushing Plant

6 Iron Ore and Limestone Handling and Grading Plant

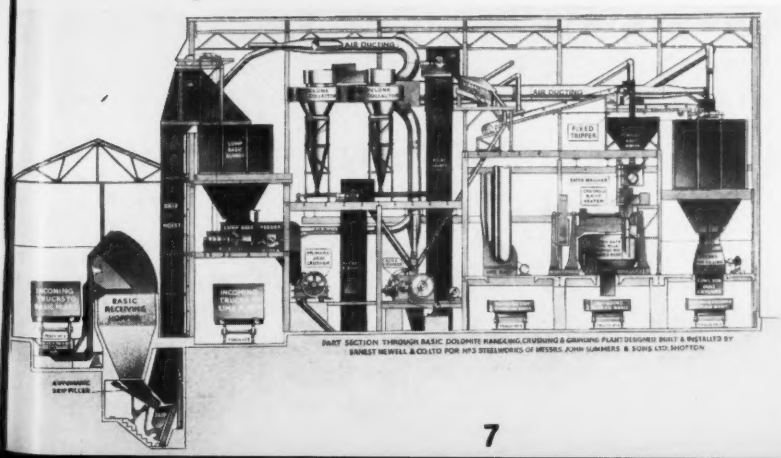
7 Complete Lime and Dolomite Crushing, Grading and Handling Plant

8 Complete Basic Slag Fertilizer Works (All machinery from Slag Bank to Packing Station)

Ernest Newell & Co. Ltd.,
MISTERTON via DONCASTER, ENG.

Designers and Manufacturers of Drying, Crushing, Grinding, Grading and Handling Plant for Steelworks Raw Macerials and By-Products.

Telegrams: Newells, Misterton, Notts, England.



PART SECTION THROUGH BASIC DOLOMITE HANDLING, CRUSHING & GRINDING PLANT DESIGNED, BUILT & INSTALLED BY ERNEST NEWELL & CO. LTD. FOR Nº3 STEELWORKS OF MESSRS. JOHN SUMMERS & SONS LTD. SHOTTON

7

8

GKB

for

PIG IRON - STEEL - CASTINGS

Basic
Hematite
Foundry

Blooms
Billets
Slabs
Sheetbar
Sections
Colliery Arches
Pit Props
Light Rails
Sleepers
Roofing Bars

Ferrous
Non-Ferrous
Up to 20 tons

GUEST KEEN IRON & STEEL COMPANY LIMITED

EAST MOORS
CARDIFF

Telephone
Cardiff 33151

Telegrams
Billets Cardiff

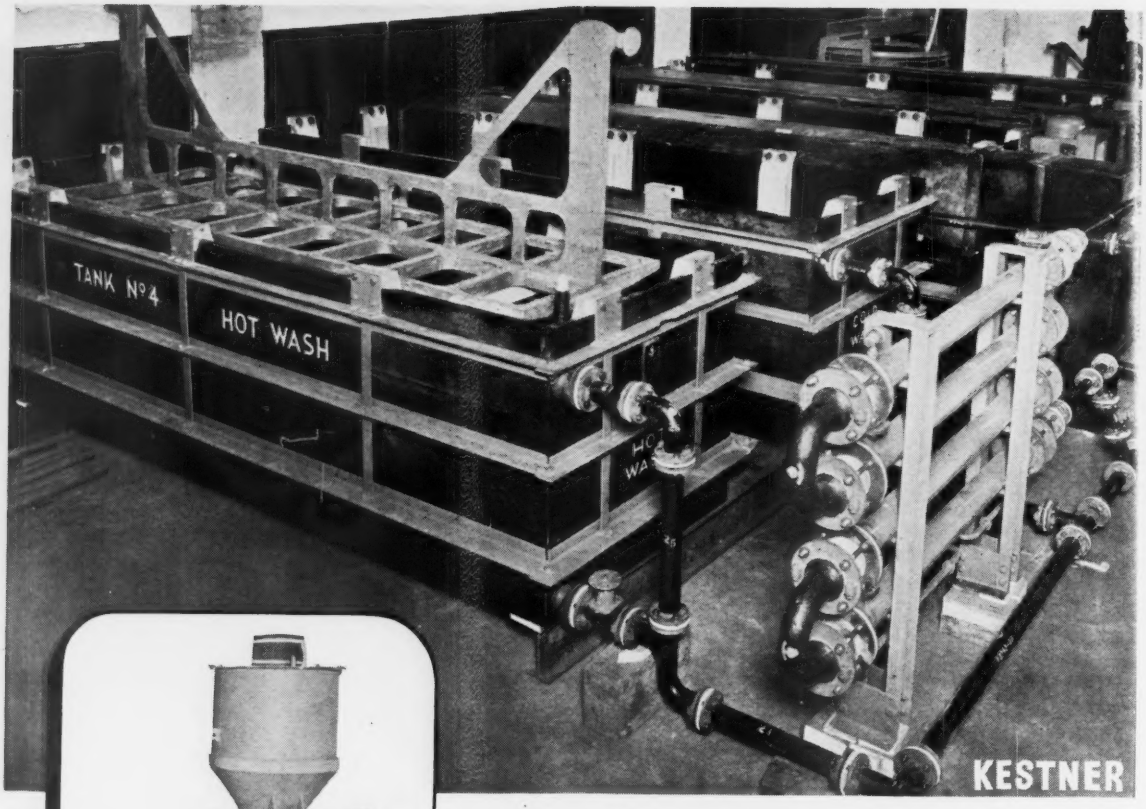
WOODALL-DUCKHAM COKE OVENS FOR NEW SCOTTISH STEELWORKS

WOODALL-DUCKHAM Construction Company Limited of London have received the order for the new coke oven plant to be built at Ravenscraig, near Motherwell, by Colvilles Limited as part of their £20 million Scottish Steel Development Scheme.

The installation, valued at about £2½ million, will carbonise 1,600 tons of coal per day and will comprise 70 W-D Becker coke ovens; coal handling storage and blending plant; coke handling and screening plant; by-products equipment; benzole recovery and rectification plant and water recirculation and cooling equipment.

WOODALL-DUCKHAM CONSTRUCTION COMPANY LTD.
Woodall-Duckham House, 63-77 Brompton Road,
London, S.W.3. 'Phone: KENsington 6355 (10 lines)
'Grams: Retortical (Southkens) London

COMPLETE PICKLING PLANT



FOR COPPER SHEET

with recovery of copper from spent pickle liquor

The Kestner organisation has over 20 years' experience in pickling processes for all industries, and thus is well fitted to advise you on your problems. We specialise in effluent disposal and acid recovery. The illustrations show a complete plant for copper pickling incorporating the Kestner Patent Copper Acid Recovery System.

KESTNER PATENT NEUTRALISER

Used for wash waters and in other instances where it is not economic to recover acid but disposal problems must be solved.

Kestner THE CHEMICAL ENGINEERS

KEEBUSH CONSTRUCTIONAL MATERIAL

KEEBUSH is used extensively in this as in other plants handling corrosive liquors. Full details will be sent at your request.

KESTNER EVAPORATOR & ENGINEERING CO. LTD. · 5, Grosvenor Gardens, London, S.W.1

Here is another M.I. Brick . . .

Morgan M.I.28 set a new standard in the manufacture of hot-face insulators — and has already saved many hundreds of tons of fuel and stepped up the output of a good many batch furnaces. Here is another brick of the same kind, from the same stable — the M.I.23.

It is a very light fireclay insulating brick with a very low thermal capacity. It will withstand a face temperature of 1260°C (2300°F) and can be used as a direct furnace lining up to this temperature: or as an insulating backing to a denser refractory such as M.R.1 or a higher temperature insulating refractory such as M.I.28.

These bricks are machined on all faces to ensure accurate furnace building and close joints.

MORGAN Refractories

ARE WORTH FAR MORE THAN THEY COST

THE MORGAN CRUCIBLE CO. LTD. (Refractories Group), Neston, Wirral, Cheshire. Telephone: Neston 1406

N.E.65

For Quality Ferro Alloys

Chromium in the form of ferro-chrome is one of the lowest cost alloying metals used by the iron and steel industry. The high carbon ferro-chrome manufactured by Bemco is renowned for its high quality, cleanliness and uniform analysis. It is specially graded and sized when necessary to customer's own specification and like the other ferro-alloys manufactured and distributed by Bemco it represents the highest quality obtainable.

BRITISH ELECTRO METALLURGICAL COMPANY

A DIVISION OF UNION CARBIDE LTD.

WINCOBANK · SHEFFIELD · ENGLAND

Telephone: Rotheram 4257

Telegrams: "BEMCO, Sheffield"

For improved ROOF LIFE

in OPEN HEARTH and ELECTRIC FURNACES

Specify **OUGHTIBRIDGE Silica Bricks**

Oughtibridge Silica Roof Bricks possess properties which give them markedly improved life over the normal Silica Brick, thus cutting the time spent on re-lining furnaces and giving increased output.

They are recommended with confidence for use in acid open hearth furnaces, for basic open hearth and electric furnace roofs, and in the linings and tuyeres of acid converters.

Technical advice and assistance on refractories will be supplied on request to all users.

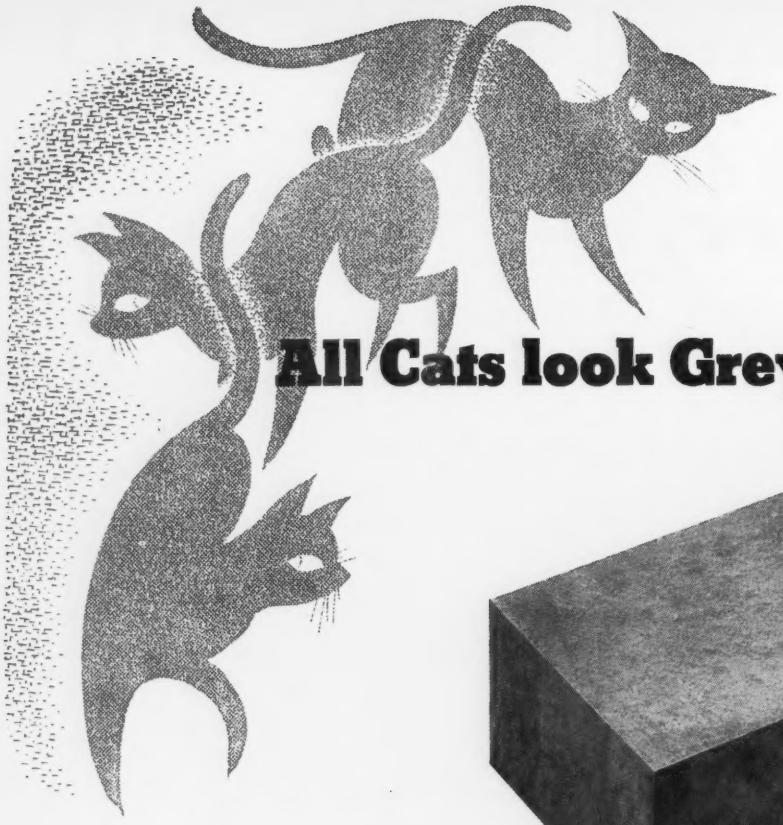
Address all enquiries to —

The OUGHTIBRIDGE SILICA FIREBRICK COMPANY Ltd

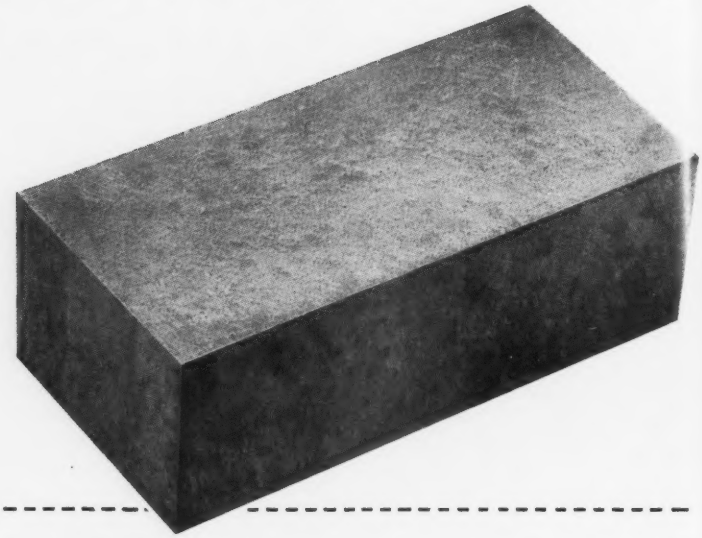
A MEMBER OF THE STEETLEY ORGANIZATION

OUGHTIBRIDGE near SHEFFIELD

Telephone: OUGHTIBRIDGE 40804 Telegrams: SILICA PHONE OUGHTIBRIDGE



All Cats look Grey in the Dark



. . . but all West Hunwick Silica bricks are the same, at any time.

UNDER LOAD REFRACTORIES TESTING APPARATUS
Constant tests are made to ensure uniformity of West Hunwick Silica Bricks.

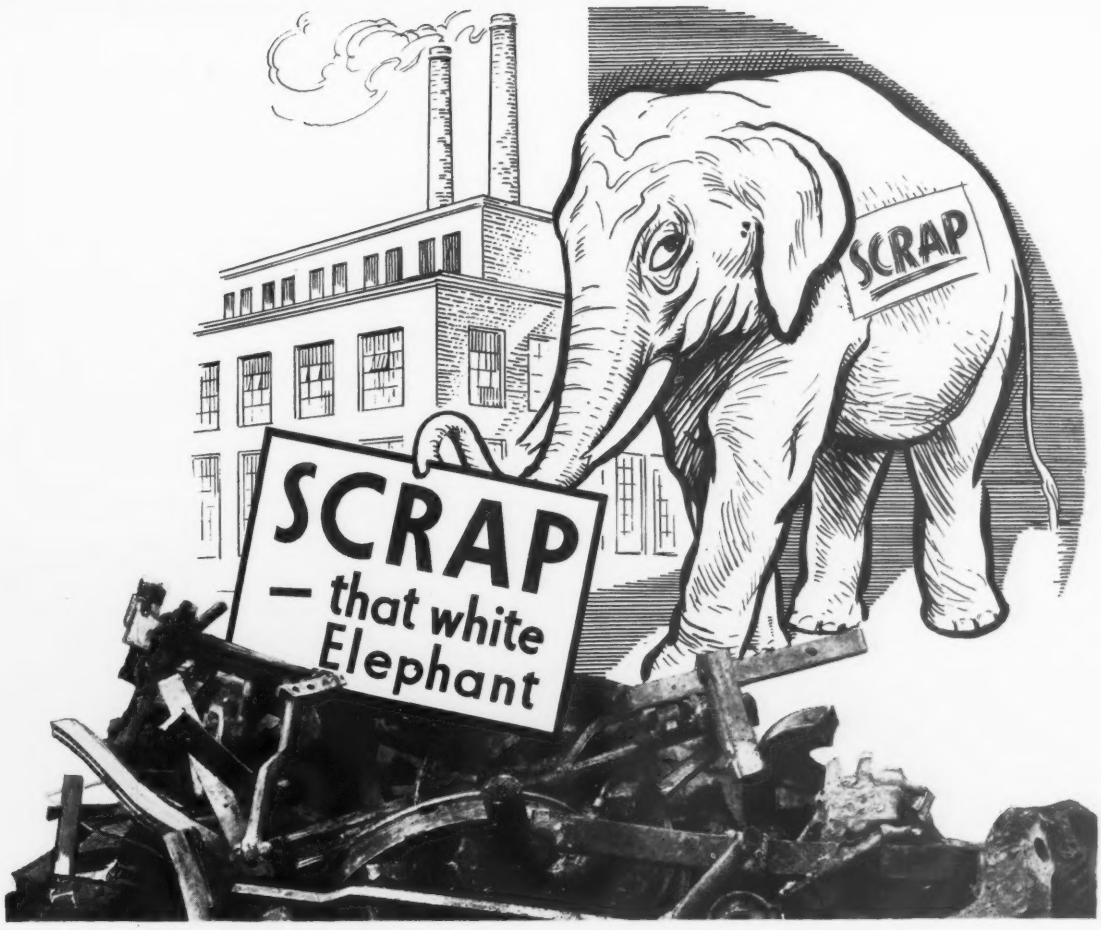
They not only look the same but they are identical in performance. There is "no possible probable shadow of doubt" that in any consignment of West Hunwick Silica bricks number one is precisely as number one-hundred-thousand-and-one. This consistency is so reliably maintained only by rigid and constant control. Our Silica brick works at West Hunwick are amongst the most modern, and most highly mechanised in the country. With automatic control at every stage of production you are assured not only of high performance but *consistently* high performance. There are no better Silica bricks made.

Also Roof Blocks made from South African Amorphous Rock a speciality.

WEST HUNWICK *Controlled* **REFRACTORIES**

THE WEST HUNWICK SILICA AND FIREBRICK COMPANY LIMITED

HUNWICK, WILLINGTON, CO. DURHAM. Tel: CROOK 200.



White Elephants in the form of obsolete plant and machinery are big game well worth the hunting. Track them down, turn them out, scrap them to make the new steel you need so urgently. Remember—scrap is worth its weight in steel—and every ton counts.

MIDDLESBROUGH Middlesbro' 3481	MILFORD HAVEN Milford Haven 76		INVERKEITHING Inverkeithing 460	BRITON FERRY Briton Ferry 3166
BIRMINGHAM Victoria 2954	BARROW Barrow 275	Ask for the SCRAP MANAGER	LIVERPOOL Boctle 3885	MANCHESTER Blackfriars 6348
PRESTON Preston 86285	BRISTOL Bristol 53253	WISHAW Wishaw 26	LONDON Albert Dock 2841	LONDON Tilbury 237

THOS W. WARD LTD
ALBION WORKS · SHEFFIELD
TELEPHONE 26311 (22 LINES) · TELEGRAMS FORWARD SHEFFIELD
LONDON OFFICE: BRETTENHAM HOUSE · LANCASTER PLACE · STRAND · W.C.2

S/13

Having a hand in Productivity

24,000 r.p.m. for a good finish

A high speed routing machine cuts out complicated shapes—not only in wood, but also in brass, aluminium and aluminium alloys. Not merely one piece but repetition work—every piece exactly the same, and every piece with a good finish; so good that no other operation is needed. And the time is generally measured in seconds. Compare this with the time and cost of other machining methods or with the cost of press tools: productivity is the word for the high speed router, but it is

only one of the aids to higher productivity that Electricity can bring you.

IN EVERY INDUSTRY OR TRADE, electrical equipment is the key to modern production methods. There are probably more production-boosting and money-saving devices than you know of. Your Electricity Board can help you and give you sound advice.

They can also make available to you, on free loan, several films on the uses of electricity in Industry — produced by the Electrical Development Association.

E.D.A. are publishing a series of books on " Electricity and Productivity ". Four titles are available at the moment; they deal with Higher Production, Lighting, Materials Handling, and Resistance Heating. The books are 8/6 each (9/- post free) and the Electricity Boards (or E.D.A. themselves) can supply you.

The British Electrical Development Association,
2 Savoy Hill, London, W.C.2

Electricity a Power of Good for PRODUCTIVITY

Ships that run on rails

It is imaginative, perhaps, to suggest that our fine British ships run on land-bound rails. Yet there is some truth in the thought. Is it not true that ships are made of steel, which in turn is manufactured from iron-ore and coal and limestone? These raw materials are taken *by rail* to the mills, and the steel plates into which they are made are sent *by rail* to the shipyards. And railways carry ships' cargoes, too!

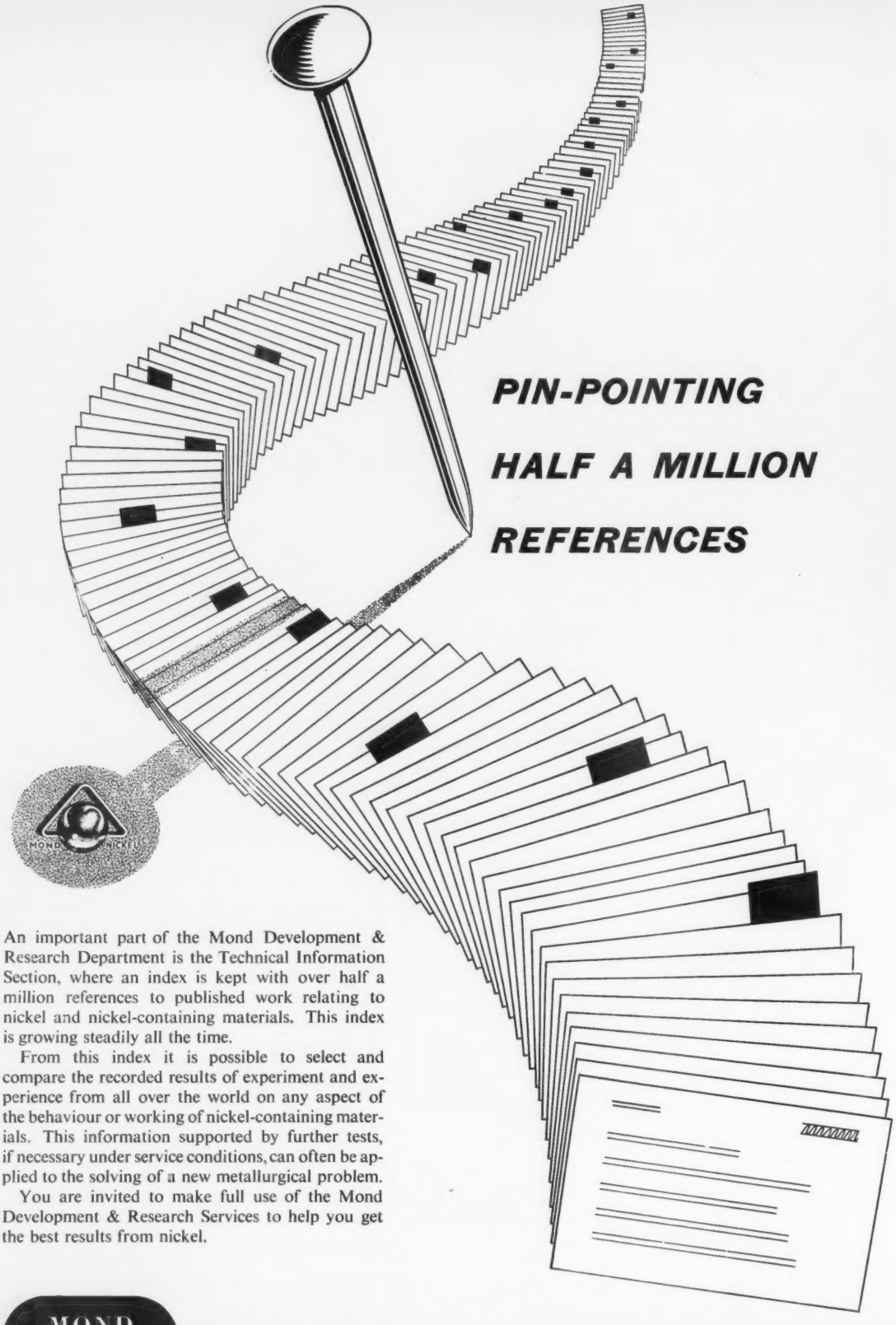
The industries of Britain owe much to the extensive and efficient network of sidings which serve the country. And, during the last one hundred and twenty years, Summersons are proud to have played so large a part in their design, manufacture, installation and maintenance.

Summersons Platelayers' Guide. Price 12/6 *Post Free.*

See Summersons for Sidings

Thomas Summerson & Sons, Ltd., Darlington, Co. Durham. Phone: Darlington 5226. And at 5a Dean's Yard, London. S.W.1. Phone: Abbey 1365

Print for Industry Ltd. Advertisement



PIN-POINTING HALF A MILLION REFERENCES

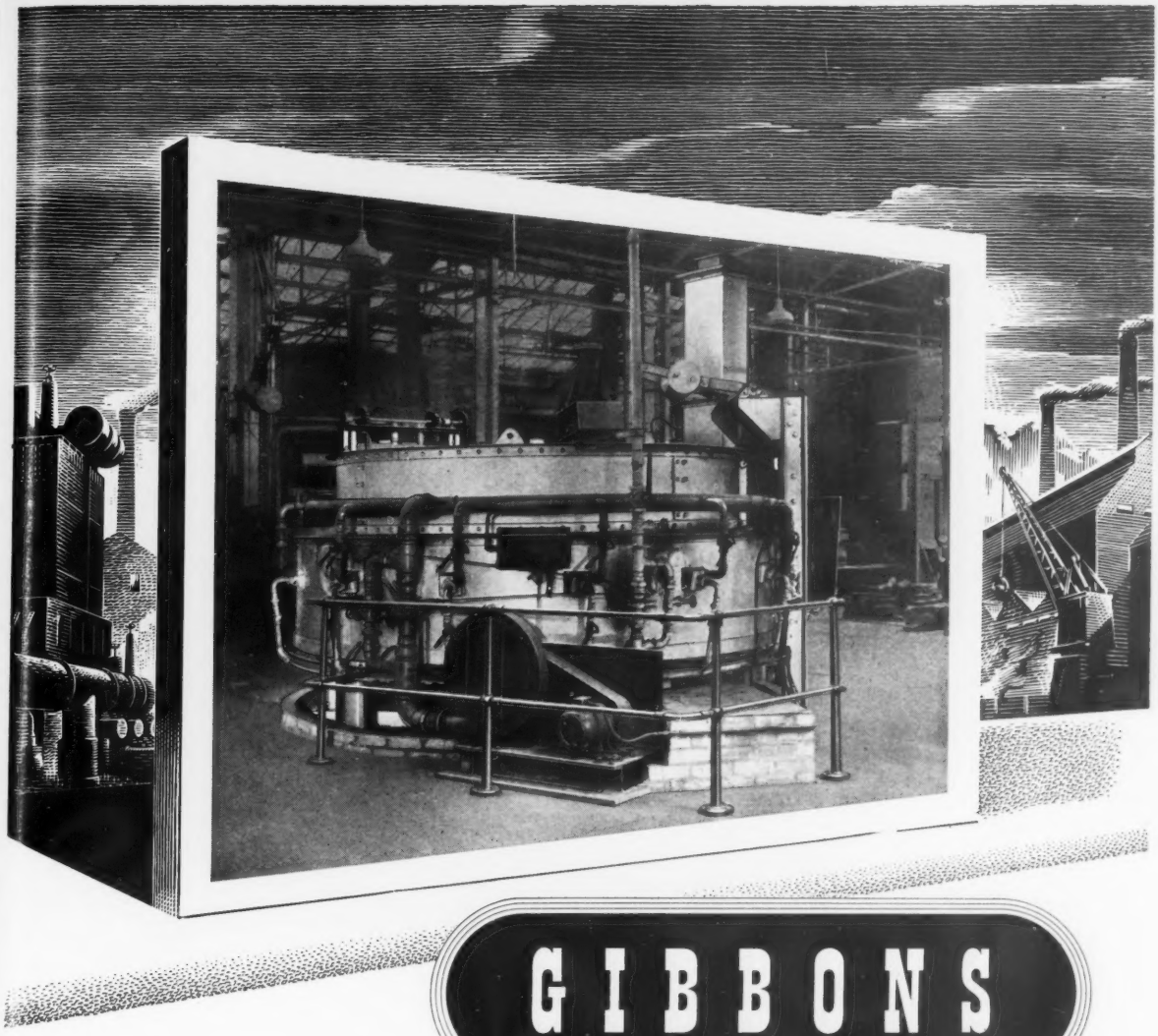
An important part of the Mond Development & Research Department is the Technical Information Section, where an index is kept with over half a million references to published work relating to nickel and nickel-containing materials. This index is growing steadily all the time.

From this index it is possible to select and compare the recorded results of experiment and experience from all over the world on any aspect of the behaviour or working of nickel-containing materials. This information supported by further tests, if necessary under service conditions, can often be applied to the solving of a new metallurgical problem.

You are invited to make full use of the Mond Development & Research Services to help you get the best results from nickel.

THE MOND NICKEL COMPANY LIMITED · SUNDERLAND HOUSE · CURZON ST · LONDON · W.1

13/GN/1



GIBBONS

EQUIPMENT

For Efficiency and Fuel Economy

DESIGNERS AND MANUFACTURERS OF :

FURNACES AND HANDLING PLANT, GAS PRODUCERS,

COKE OVENS, GAS WORKS PLANT, DRESSLER TUNNEL

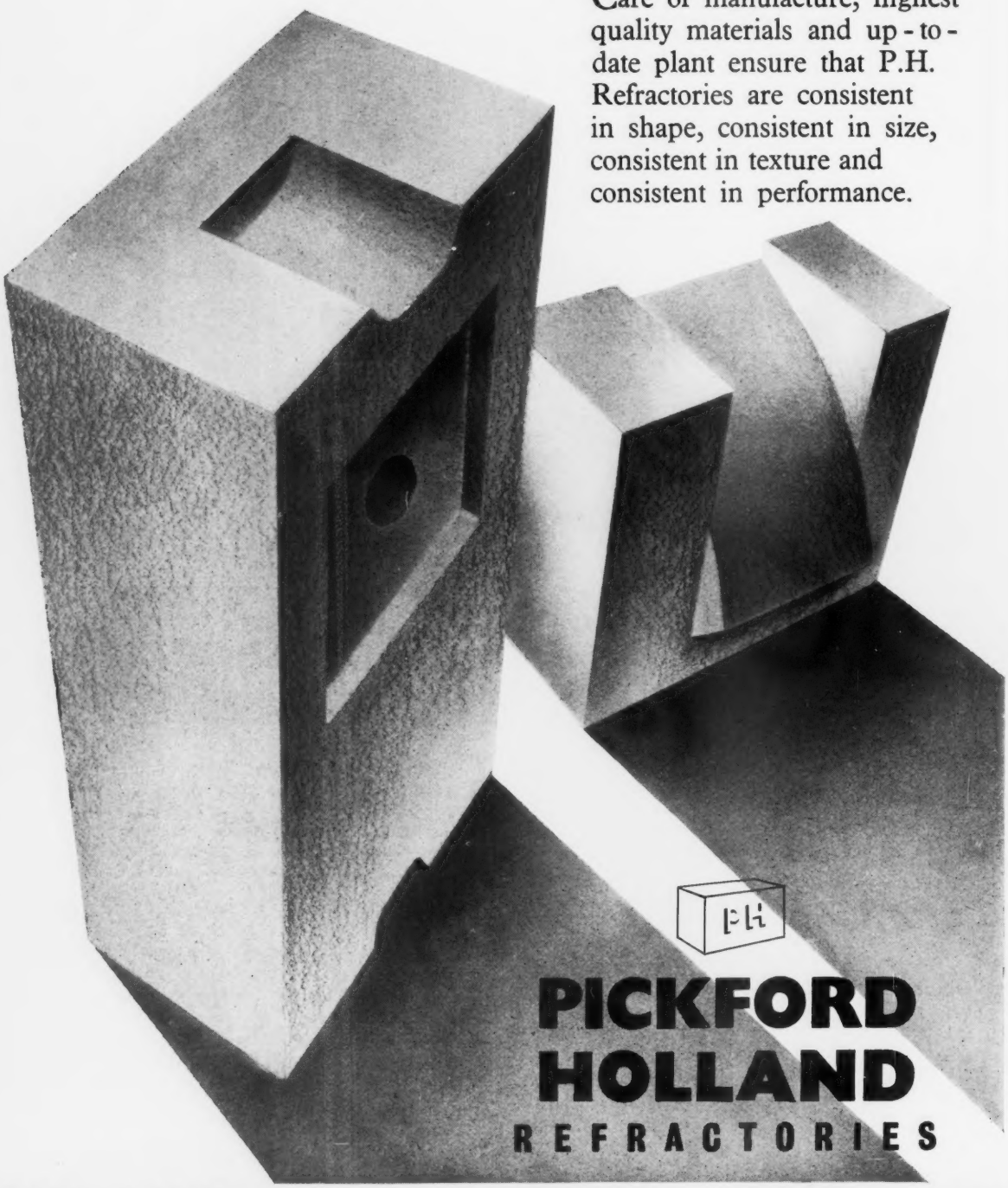
KILNS AND REFRACTORIES

GIBBONS BROTHERS LTD. DIBDALE WORKS · DUDLEY · WORCS.

Telephone : DUDLEY 3141

Refractories
of all Shapes and Sizes

Care of manufacture, highest quality materials and up-to-date plant ensure that P.H. Refractories are consistent in shape, consistent in size, consistent in texture and consistent in performance.



Pickford, Holland & Co. Ltd., Sheffield **Telephone 31721**

ADAMSON-ALLIANCE

Steel works AA equipment

Manufacturers of

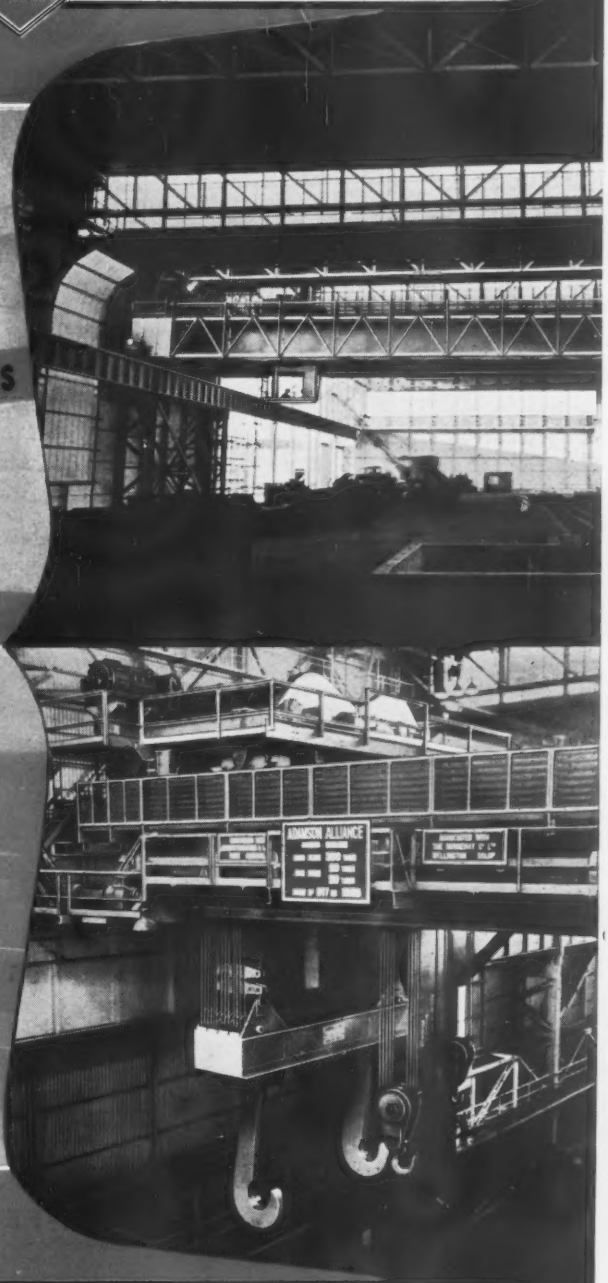
LADLE & GANTRY CRANES

SOAKING PIT & STRIPPING CRANES

OVERHEAD TRAVELLING CRANES

CHARGING MACHINES

FORGING MANIPULATORS



ADAMSON-ALLIANCE CO. LTD.

INCORPORATING THE STEELWORK DIVISIONS OF:
JOSEPH ADAMSON & CO., LTD., HYDE, CHESHIRE. THE HORSEHAY CO., LTD., WELLINGTON, SALOP.
THE ALLIANCE MACHINE COMPANY, ALLIANCE, OHIO, U.S.A.

HEAD OFFICES: 165, FENCHURCH STREET, LONDON, E.C.3. TELEPHONE: MANSION HOUSE 1626

BRIGHTSIDE

Photograph by courtesy of Messrs. Thos. Firth & John Brown Ltd., Sheffield.

STEELWORKS PLANT AND AUXILIARIES

HOT AND COLD ROLLING MILLS

HOT AND COLD ROLLS FOR FERROUS AND NON-FERROUS ROLLED PRODUCTS

THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD.

SHEFFIELD P.O. BOX 118

BS.41

COAL PREPARATION

COKE OVEN PLANT

AND BY-PRODUCT PLANT

POWELL DUFFRYN-COPPEE LTD.

19, BERKELEY STREET, LONDON, W.1

GROSVENOR 3801

BRIGHTSIDE

Photograph by courtesy of Messrs. Thos. Firth & John Brown Ltd., Sheffield.

STEELWORKS PLANT AND AUXILIARIES

HOT AND COLD ROLLING MILLS

HOT AND COLD ROLLS FOR FERROUS

AND NON-FERROUS ROLLED PRODUCTS

THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD.

SHEFFIELD P.O. BOX 118

BS.41

COAL PREPARATION

COKE OVEN PLANT

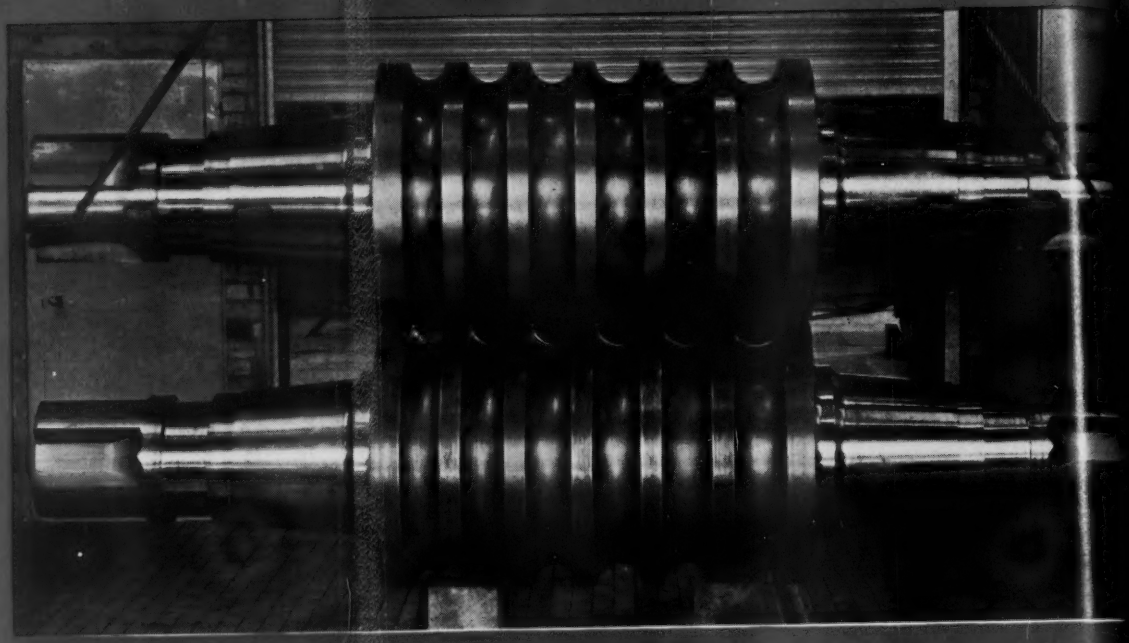
AND BY-PRODUCT PLANT

POWELL DUFFRYN-COPPEE LTD.

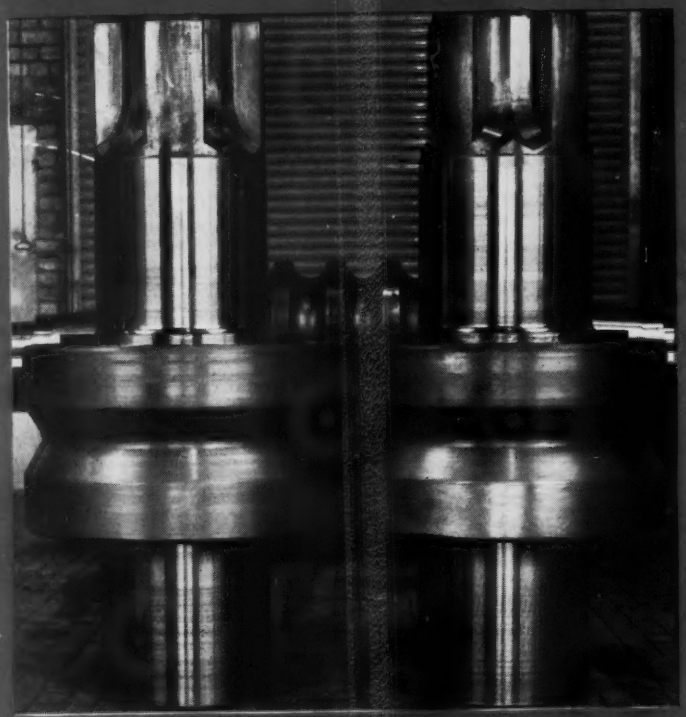
19, BERKELEY STREET, LONDON, W.1

GROSVENOR 3801

INCREASED TONNAGE WITH



A pair of our Special "SSXH" Mooralloy Quality Rolls for Finishing Large Rounds 4½" to 6" dia. for No. 6 S
Roll size 32" dia. x 54" long barrel.



The Specialised Products include:

CHILL AND ALLOY CHILL ROLLS F
HOT & COLD ROLLING ALL CLAS
OF STEELS FOR SHEETS, ST
SECTIONS,
AND
NON FERROUS METALS

SPECIAL ROLLS FOR STAINL
STEEL ROLLING.

PART CHILL, GRAIN & ALLOY GR
ROLLS

ALSO THE **S.G.** RANGE O
SUPER TOUGH SPHEROIDA
GRAPHITE ALLOY IRON ROL

No. 5 Vertical Edging Stand in our Moor
"SSXM" Quality for Billet train (diamond
Leader for 2" to 4" Billets.
Roll size 31¼" dia. x 18" long barrel.

THE ROLL MAKERS

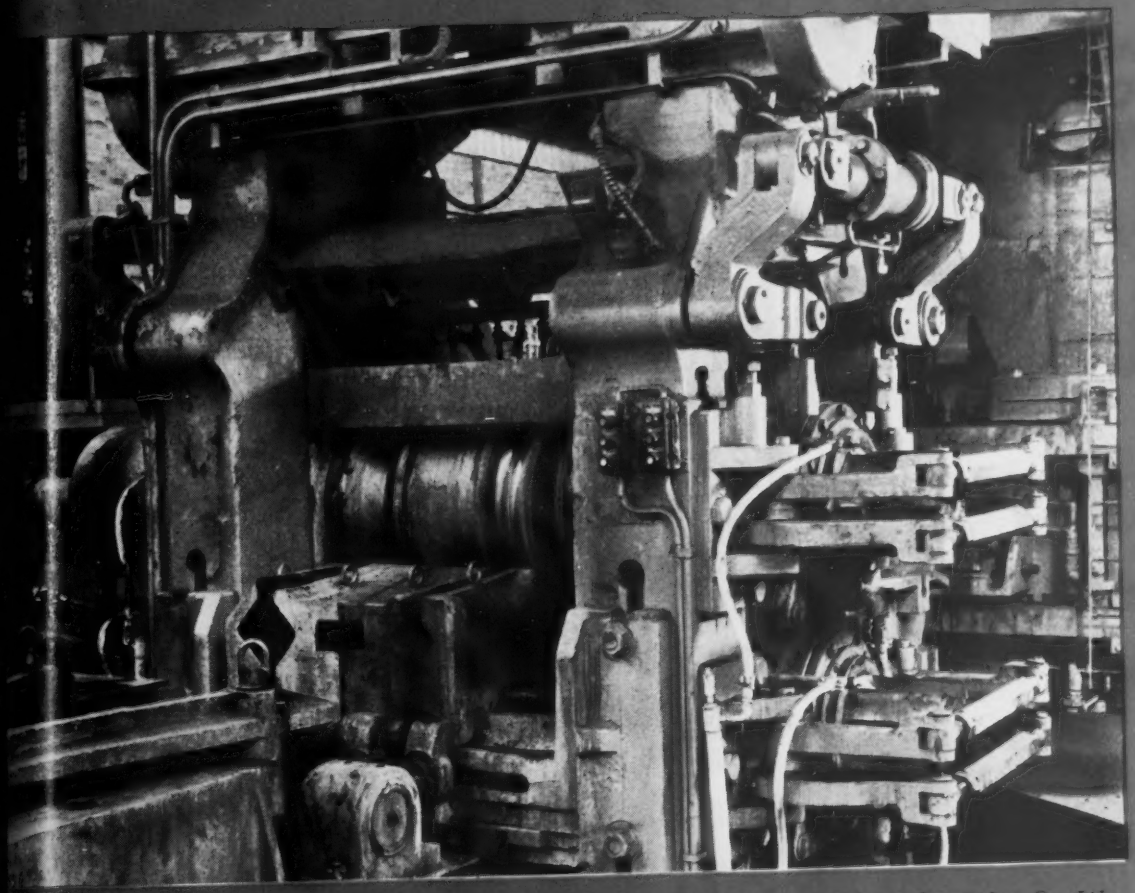
JOHN. M

EAGLE FOUNDRY • STEVENSON RO

TELEPHONE: SHEFFIELD 42018

MOORALLOY

THE SUPER ROLL METAL



Stand Finishing for 4", 4½" and 5" Billets, also Roughing for 2" to 3½" Billets and Slabs at Consett Iron Co., Ltd., showing our Special S.S.X. Mooralloy Quality Rolls. Roll size 32" dia. x 54" long barrel.

Photographed by the courtesy of The Consett Iron Co. Ltd.

Considerable economies in materials, production time and maintenance costs can be effected by the use of our Mooralloy Rolls for Continuous Mills, idle time resulting from the need for redressing is reduced to a minimum.
It is necessary to select the correct quality from the very wide range now available to suit all the conditions in modern mill practice.

The "SSX" Range of Tough Metal
"SSX", "SSXM", "SSXH".

The "XL" Range of Tough Medium Hard Metal
"XLM", "XL", "XLH".

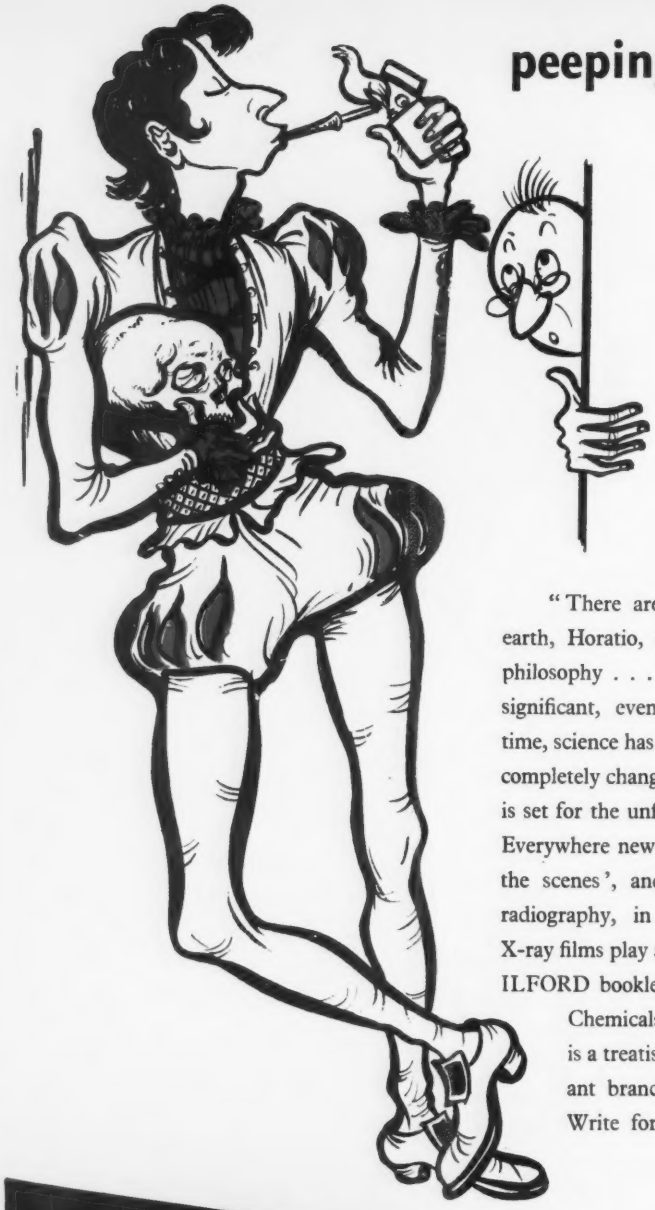
The "XXL" and "XXXL" Ranges of Hard Superfine Close Texture Metal
"XXL", "Super XXL", "XXXL", "Super XXXL".

WHY NOT CONSULT US NOW?

HOORWOOD LTD

ATTERCLIFFE • SHEFFIELD 9

TELEGRAPHIC ADDRESS: CHILROLS, SHEFFIELD, 9



peeping behind the scenes . . .

"There are more things in heaven and earth, Horatio, than are dream't of in your philosophy . . ." Hamlet's words are still significant, even though since Shakespeare's time, science has lifted curtain after curtain and completely changed the scene. Today the stage is set for the unfolding of still more mysteries. Everywhere new methods are 'peeping behind the scenes', and none more searching than radiography, in which ILFORD Industrial X-ray films play a leading part. By the way, the ILFORD booklet "X-ray Films, Screens and Chemicals for Industrial Radiography" is a treatise in miniature on this important branch of non-destructive testing. Write for a free copy today.

ILFORD **Industrial X-ray films**

in the service of Industry

ILFORD LIMITED · ILFORD · LONDON

ELECTRIC IGRANIC CO. LTD

. . . FOR BETTER MAGNET PERFORMANCE

HELPFUL HINTS TO USERS OF IGRANIC MAGNETS

FOR PEAK EFFICIENCY IN MAGNET PERFORMANCE, FOR TROUBLE-FREE MAGNET OPERATION, FOR LONGER MAGNET LIFE

KEEP THE POWER OFF UNTIL MAGNET SETTLES ON PILE

If you *don't*, smaller pieces will jump up to magnet and block off the rest so that you *can't* get a full load.

WORK ON DEEP PILES . . . YOU GET A BIGGER LOAD

The magnetism has a chance to take a full deep " bite " out of the pile.

KEEP BOLTS TIGHT

And replace broken bolts. Helps to keep moisture out, protects pole shoe against mechanical shock and helps to keep lifting power at maximum.

GREASE CHAIN LINKS AND KEEP THEM GREASED

Chain links constantly rub against each other causing friction and wear. Keep the links greased, keep friction down and your chains will last much longer.

DON'T USE MAGNET AS A BATTERING RAM

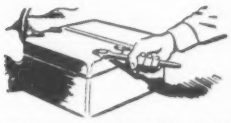
You may break a pole shoe, a terminal box, damage the windings, or rupture the insulation inside the magnet. *Use the magnet only for lifting.*

DON'T USE MAGNET AS SKULL-CRACKER

Many magnets don't wear out. They are broken—by careless handling. Don't drop a magnet to break up heavy pieces of scrap or to loosen a frozen ingot. *Use it only for lifting.*

SET YOUR MAGNET DOWN EASY

Repairs to broken magnets can be expensive and use up precious time. Ease your magnet down on to the pile.



KEEP TERMINAL BOX CLOSED

Keeps moisture away from terminals and protects them against breakage. If cover is lost, get a new one.

KEEP THE POWER OFF ON THE RETURN TRIP

The current heats the magnet and a hot magnet will not carry as much as a cool magnet. So discharge the load fast, keep the current " off " during the return trip, keep the magnet cool.

WHEN HANDLING HOT MATERIALS

Watch magnet temperature carefully and switch to spare magnet to avoid overheating.

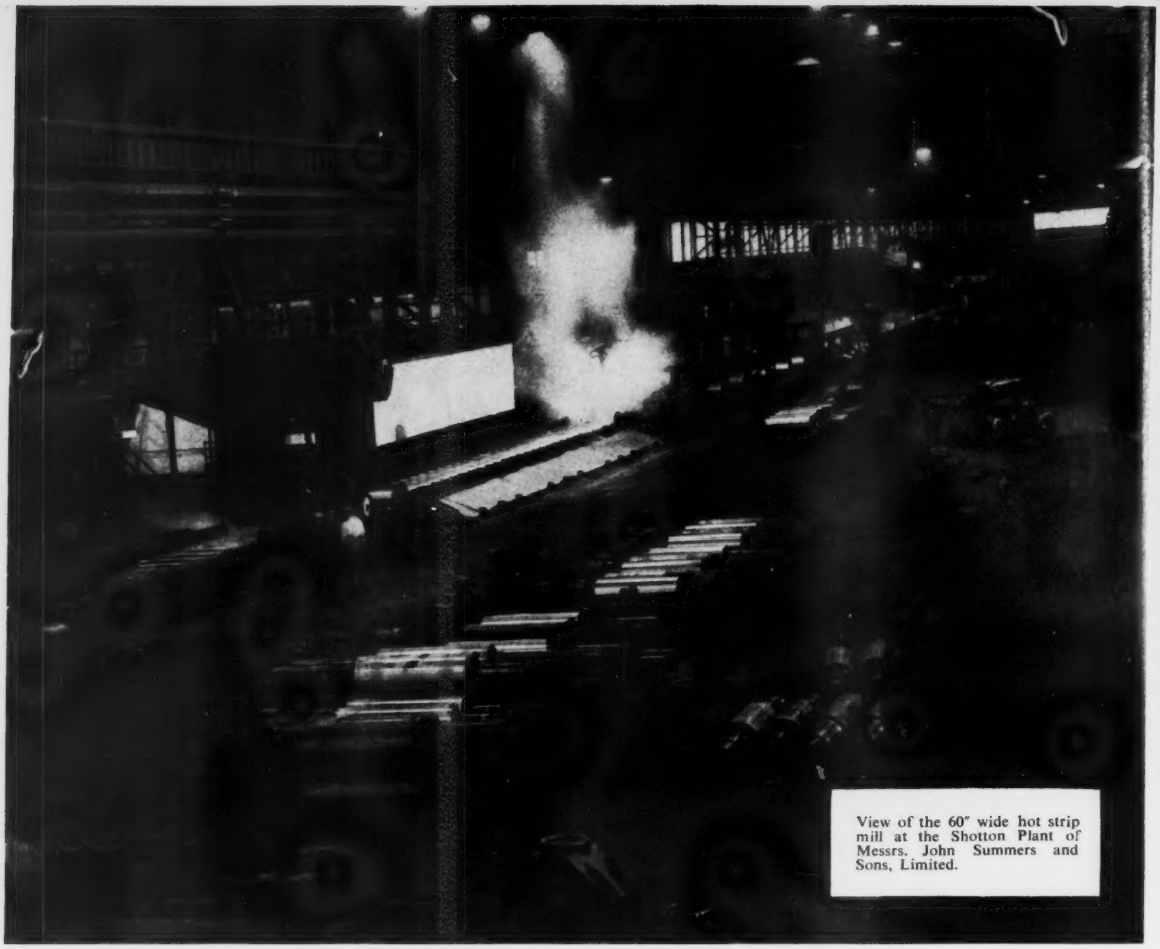
INSTRUCTION SHEET 61113 SI, PRINTED ON HEAVY CARD FOR HANGING IN YOUR CRANE CABIN, CONTAINS 13 USEFUL OPERATION AND MAINTENANCE TIPS. COPIES CAN BE OBTAINED FREE ON APPLICATION TO PUBLICITY DEPARTMENT, BEDFORD.

IGRANIC ELECTRIC CO. LTD. HEAD OFFICE & WORKS: BEDFORD

EXPORT DEPT : VICTORIA STATION HOUSE, 191 VICTORIA ST., LONDON, S.W.1. Cablegrams: "Igranic, London"

DISTRICT OFFICES

LONDON · BIRMINGHAM · BRISTOL CARDIFF · GLASGOW · LEEDS MANCHESTER NEWCASTLE · SHEFFIELD

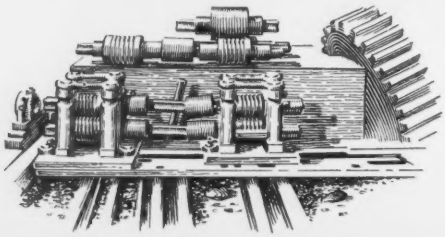


View of the 60″ wide hot strip mill at the Shotton Plant of Messrs. John Summers and Sons, Limited.

Photograph reproduced by courtesy of Messrs. John Summers & Sons, Ltd.

The history of England is the history of Progress

(Macauley)



Henry Cort's Mill at Wortley 1790

Henry Cort's primitive mill with the crude rolls he used foreshadowed the metallurgical and technological marvels that are the rolling mills of today. This progress is due in no small measure to the efforts of the British Rollmakers Corporation—the leaders of the rollmaking industry in Britain.

BRITISH
ROLLMAKERS
CORPORATION LIMITED

MASTERS OF THE ROLL

BRITISH ROLLMAKERS CORPORATION

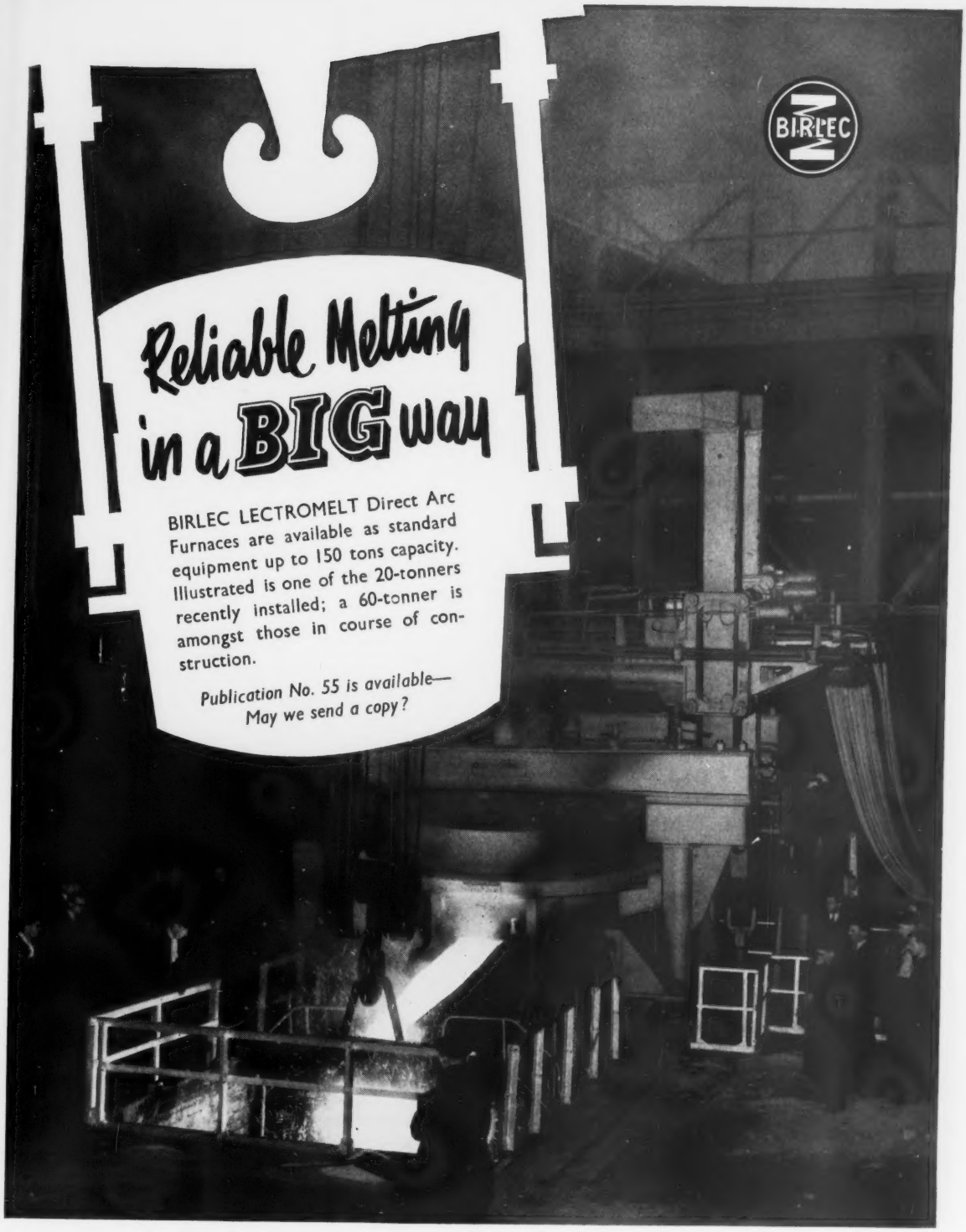
TENNENT
R. B. Tennent Ltd.,
Whifflet Foundry,
Coatbridge,
Scotland.

AKRILL
C. Akrill Ltd.,
Gold's Green
Foundry,
West Bromwich.

PERRY
Thomas Perry Ltd.,
Highfields Works,
Bilston.

MIDLAND ROLLMAKERS
Midland Rollmakers Ltd.,
Weston Road,
Crewe.

London Offices: 38 Victoria Street, S.W.1. 'Phone Abbey 6407.


BIRLEC
Reliable Melting
in a BIG way
BIRLEC LECTROMELT Direct Arc Furnaces are available as standard equipment up to 150 tons capacity. Illustrated is one of the 20-tonners recently installed; a 60-tonner is amongst those in course of construction.
Publication No. 55 is available—
May we send a copy?

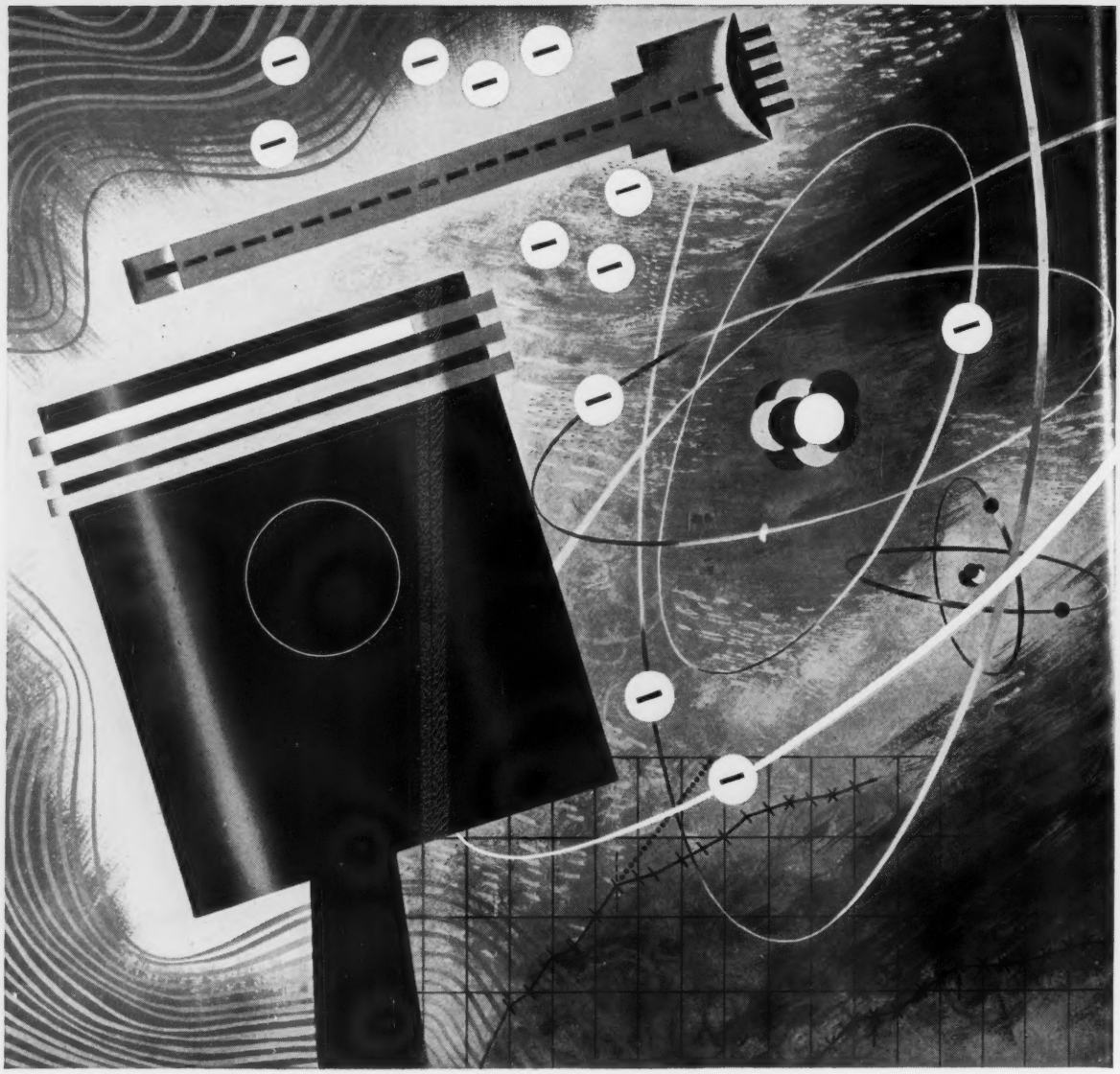
BIRLEC

BIRLEC LIMITED

ERDINGTON · BIRMINGHAM · 24

Sales and service offices in LONDON · SHEFFIELD · GLASGOW and NEWCASTLE-ON-TYNE

sm/B. 1011. 53a



Atomic detectives

Metal wear is no new problem to engineers or research workers, but the work at Thornton has been transformed almost overnight by the application of radioactive isotopes to wear study. These are the atomic detectives of science. They record the slightest fingerprint of wear with inhuman speed and accuracy.

In a test now proceeding, a radioactive piston ring fitted in an experimental engine is supplying valuable data on the *rate* of wear. Wear on the piston ring removes minute particles of radioactive metal which are carried away by the lubricating oil. As the oil returns to the sump of the engine it passes a Geiger Counter, which automatically records the presence of radioactive metal. This fundamentally simple test is likely to give remarkable results, results that will be turned to practical account by Shell scientists and engineers.

In another test, a length of wire is drawn vertically through a tungsten carbide die which has been made radioactive. Normally, the wear on the die using different wire-drawing lubricants is measurable only when about two miles of wire have been drawn, but with the aid of radioactive tracers, which are transferred from the die to the wire, the radioactivity of the wire can be assessed by means of a Geiger Counter. By this method it is possible to measure 0.00000002 grams of die wear per foot length of wire.

These are but two examples of how work on the atom has given into the hands of Shell lubrication experts research aids that will give answers in weeks instead of years. To you that means even better performance from even better Shell lubricants. To industry as a whole it means a narrowing of the time-lag between the invention of new machines and the development of lubricants to suit them.

Shell's laboratories at Thornton, Cheshire, cover an area of 800,000 sq. ft. and are manned by a staff of over 800—that's how Shell makes sure.

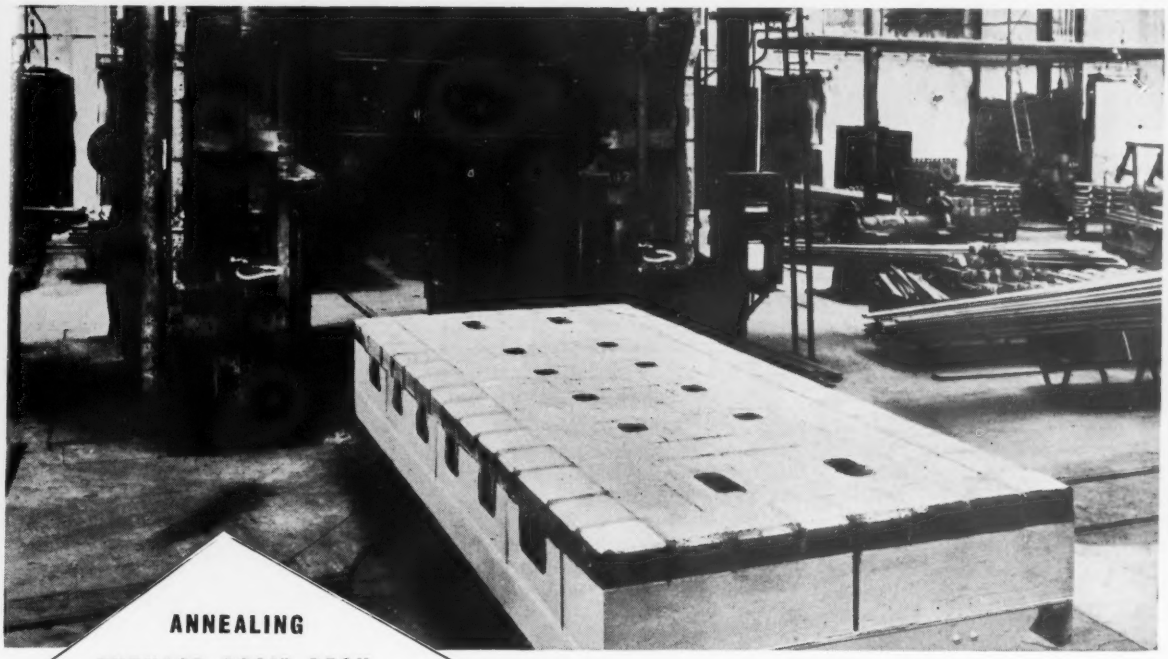
SHELL

LEADERSHIP IN LUBRICATION

works engineers have many uses for

REFRACTORY CONCRETE

The adaptable Refractory Material The low cost and extreme adaptability of its many properties explain the tremendous growth in the use of Refractory concrete in all types of Works. The many applications include foundations, door linings, repairs to producer linings, charge hole blocks, retort setting, flues, retort house quenching floors, coke shoots, top paving, carburettor head tiles, dampers, lids, brick setting, crucible furnaces, melting furnaces, coke oven doors, coke oven pipe linings, furnace arches, etc.



ANNEALING FURNACE BOGIE DECK (IN PRE-CAST SHAPES)

Photograph by courtesy of Messrs. Hurst, Nelson & Co. Ltd.

Refractory Concrete

Is Refractory aggregate bonded with Ciment Fondu high-alumina cement.
Is ready for use and of great strength and hardness in 24 hours.
Can be used to reduce joints to a minimum.
Can be cast to any shape. Requires no pre-firing.
Is stable under load up to 1,300°C. Has a melting point of about 1,450°C.
Has no appreciable drying shrinkage or after-contraction.
Can be brought to working temperatures 24 hours after making.
Does not spall under widest sudden fluctuations of temperature.
Pre-cast blocks or special shapes can be made of practically any size or shape without distortion or cracking.
Uses old scrap firebrick to a very large extent.
Provides an ideal bond for setting firebricks.

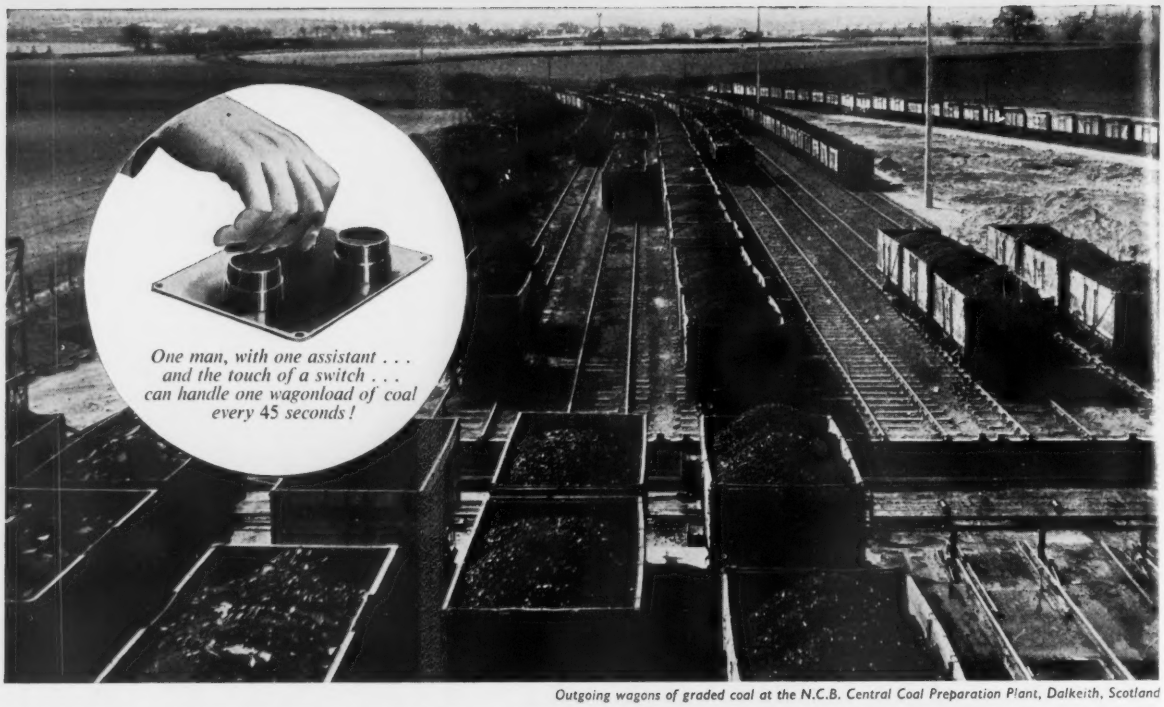
Send for further details including one of our Refractory Charts giving mixes for various purposes.

Concrete Rock-Hard within one day

CIMENT FONDU
Registered Trade Mark
ALUMINOUS CEMENT

LAFARGE ALUMINOUS CEMENT CO. LTD. 73 Brook Street London, W.1. Telephone Mayfair 8546

3/1209



Outgoing wagons of graded coal at the N.C.B. Central Coal Preparation Plant, Dalkeith, Scotland

NEW APPROACH TO WAGON HANDLING

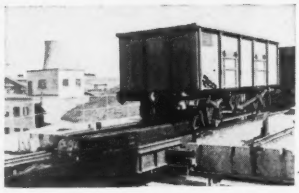
. . . Mitchell system means smaller sidings, quicker turnround, less gear, greater safety

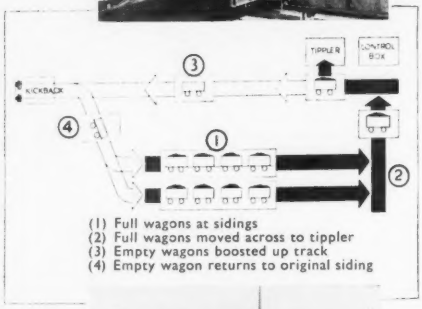
How many men work on your coal sidings? How many locomotives or capstans? What space is wasted by sprawling tracks? How much tonnage can you handle per hour?

The generally unsatisfactory answers given to such questions as these inspired the design of the Mitchell system of wagon handling—a mechanical, electrically-controlled system that offers remarkable scope for increased efficiency at power stations, collieries, coal preparation plants, steelworks, etc., and other centres of industry possessing marshalling yards.

The Mitchell system can be operated by two men. It takes wagons from the arrival sidings, loads or unloads them, weighs them and remarshals ready for departure. Wagons can be emptied and returned to the same siding they arrived at "full" so that one track is used for full and empty wagons. No internal shunting, no additional motive units, no man-handling other than initial uncoupling and final recoupling, are required. The system has no limit to size or capacity and can easily handle the 1000 tons or more of coal per hour which is now being called for. And it does it with the highest degree of safety, in all weathers, round the clock if needs be.

By demanding no more than half the space occupied by traditional balloon sidings, the Mitchell system makes possible the erection of new plant on sites hitherto unsuitable, with very large savings in initial and later costs. Its flexibility makes it adaptable to any individual handling problem. Installations are already at work for the National Coal Board and the British Electricity Authority. The thoroughgoing efficiency and economy of the Mitchell system puts it far in advance of any traditional method and establishes it as the system of the future.



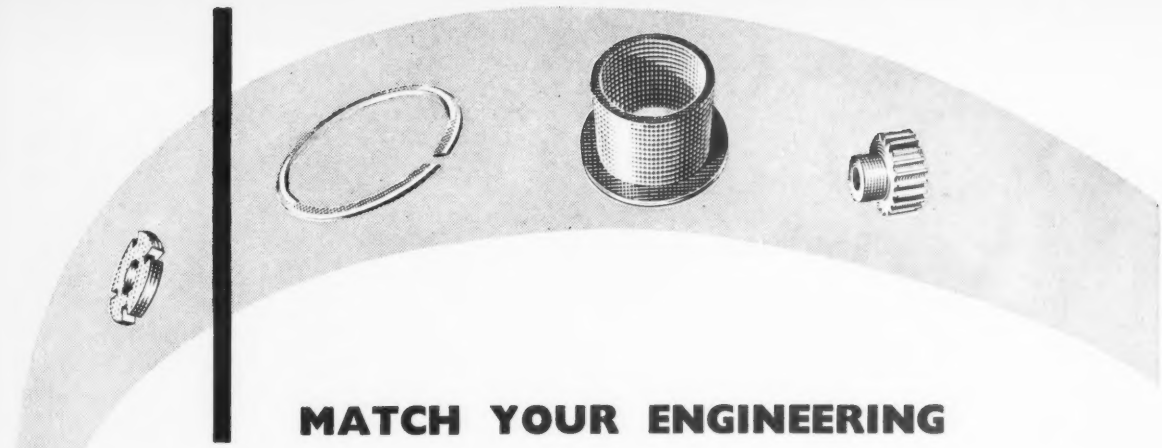


(1) Full wagons at sidings
(2) Full wagons moved across to tippler
(3) Empty wagons boosted up track
(4) Empty wagon returns to original siding

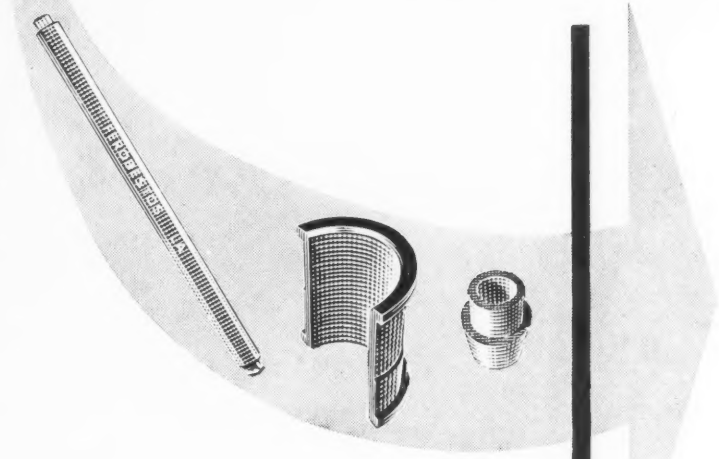
An installation at the British Electricity Authority, Freemens Meadows, Leicester, handling 800 tons of coal an hour. The site is limited in area and normal methods of working with balloon sidings would be impractical. The pictures show the traverser pulling an incoming truck on to the transfer rail and an emptied wagon being returned to the siding by the 'kickback'.

MITCHELL ENGINEERING LIMITED
ONE BEDFORD SQUARE · LONDON · WC1

4937



MATCH YOUR ENGINEERING PROBLEM AGAINST THIS SPECIFICATION . . .



- *a* High wear resistance
- *b* High temperature resistance (up to 200° C. or 400° C. if Silicone-bonded)
- *c* High Chemical resistance
- *d* High strength in proportion to weight
- *e* Good electrical resistance
- *f* Dimensionally stable
- *g* Low moisture absorption
- *h* Low starting and running friction — particularly when lubricated by water

...and the answer is

FEROBESTOS

TECHNICAL PLASTICS

the non-metallic, laminated asbestos plastics that meet the needs of modern industry.

FERODO LIMITED · CHAPEL-EN-LE-FRITH · *A Member of the Turner & Newall Organisation*

HOT ROLLED STEEL

Hoops, Strip and Bars

Round • Square • Flat

Ferro-Concrete Bars *bent to specification*

BRIGHT DRAWN STEEL BARS

For all purposes

SPECIALITY :—

WHISCO (REG'D) BRAND.

COLD ROLLED STEEL STRIP

in all qualities including

Special Deep Stamping
in cut lengths or coils
Electro-Galvanised Strip

Speciality :

VERY HEAVY CONTINUOUS LENGTH COILS

WHITEHEAD IRON & STEEL CO LTD

Phone : 3161 Newport **NEWPORT MON** *Grams : Whitehead Newport*

LONDON OFFICE
STEEL HOUSE,
TOTHILL STREET, S.W.1
Telegrams :
WHITEDSTEL, PARL, LONDON
Telephone :
WHITEHALL 2984

BIRMINGHAM OFFICE
KING EDWARD HOUSE,
NEW STREET, BIRMINGHAM, 2
Telegrams :
WHITEDSTEL, BIRMINGHAM
Telephone :
MIDLAND 0412-3

GLASGOW OFFICE
50 WELLINGTON STREET, C.2
Telegrams :
WHITEDSTEL, GLASGOW
Telephone :
CENTRAL 1528

MANCHESTER OFFICE
CHRONICLE BUILDINGS
Telegrams :
WHITEDSTEL, MANCHESTER
Telephone :
BLACKFRIARS 3172

WEAK *at the* JOINTS

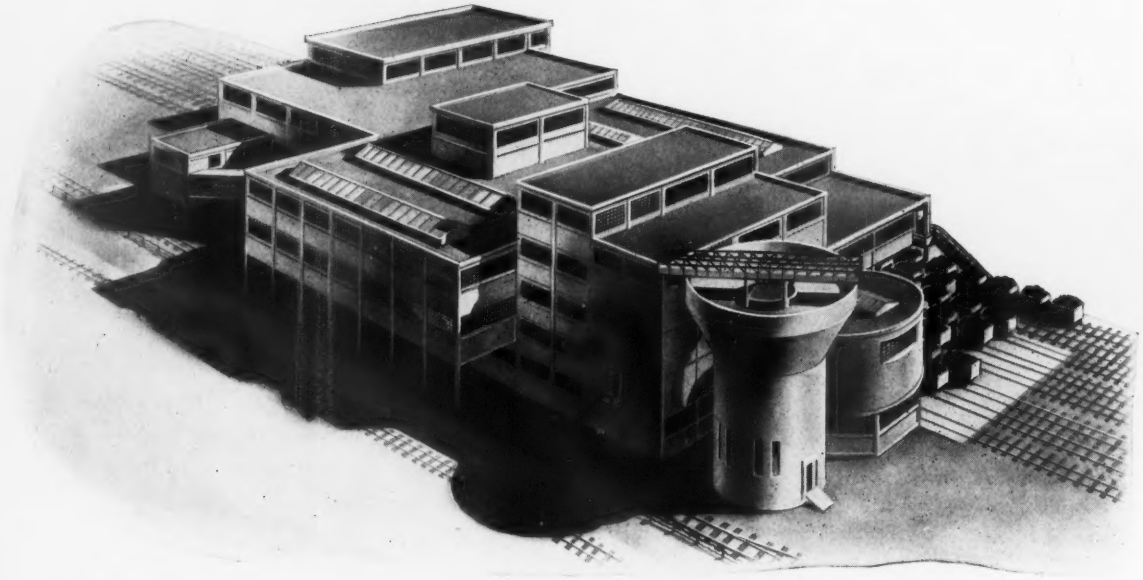
With nothing to hold it together a skeleton will soon fall apart. Human joints, so flexible and tough, are a fine example of the right material for the job. For more than 100 years Dysons have been making special refractory jointing and lining compounds to meet the requirements of the iron and steel makers.

Steel moulders' composition · Cupola Ganister Siliceous ladle jointing · High Frequency Furnace Linings · Silica Cements · Gunning Compounds · All Cements and Plastics for High Temperatures &c. &c. &c.

J. & J. DYSON LTD., STANNINGTON, SHEFFIELD

COPPEE

– the organisation with over 100 years world-wide experience



DESIGNING & CONSTRUCTING

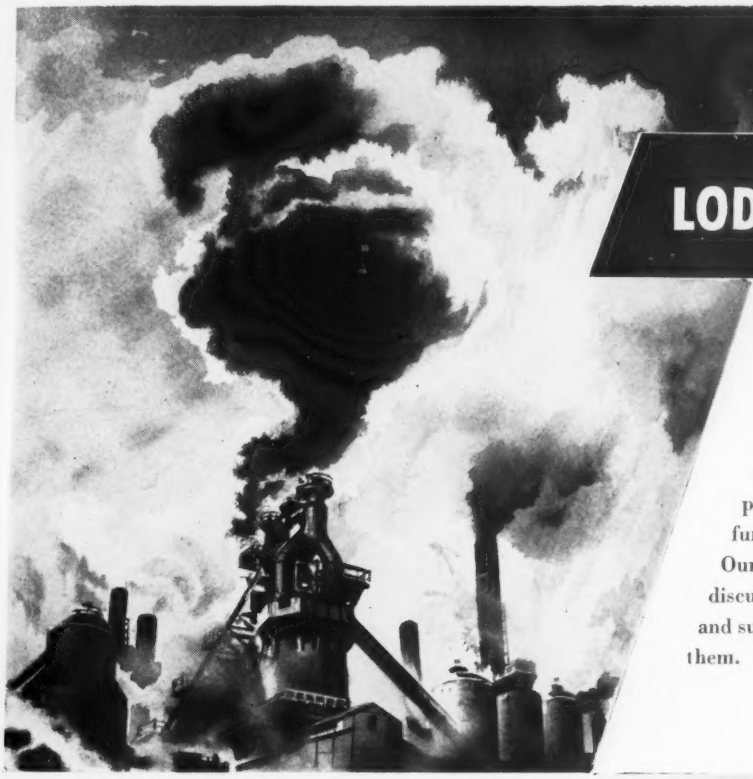
COAL PREPARATION PLANT

Coppee plant embodies flexible systems to provide the highest efficiency in coal preparation. Processes include Heavy Medium washing, Automatic Baum washing, fine coal cleaning by D.S.M. Cyclone Separators, and Slurry Treatment by Vacuum Flotation methods. Your enquiries are invited.

THE COPPEE COMPANY (Great Britain) LTD.
COPPEE HOUSE, 140 PICCADILLY, LONDON, W.1.
Telephone: GROsvenor 4976 Telegrams: Evcoppee, Phone, London

GLASGOW: 122 Wellington Street, C.2. NEWCASTLE-ON-TYNE: Mansion House Chambers, The Close.

is your problem smoke? then call in

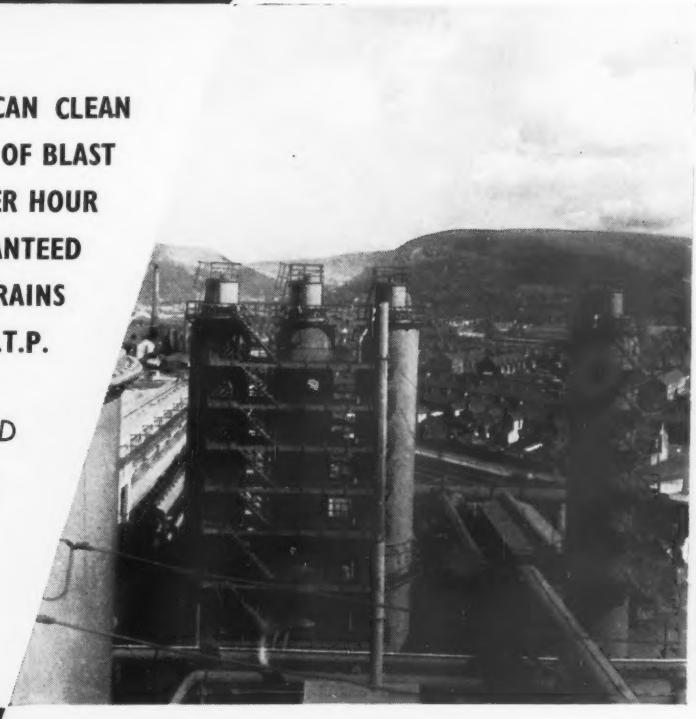


LODGE-COTTRELL

This Lodge-Cottrell Electrostatic Precipitation Plant at the Steel Company of Wales, Margam, is one of many similar installations successfully solving dust and smoke problems in steelworks and blast furnaces throughout the world. Our Advisory staff will gladly discuss with you your problems and suggest the best way of solving them.

THIS PLANT CAN CLEAN 16,000,000 CU. FT. OF BLAST FURNACE GAS PER HOUR TO WITHIN GUARANTEED LIMITS OF 0·004 GRAINS CU. FT./N.T.P.

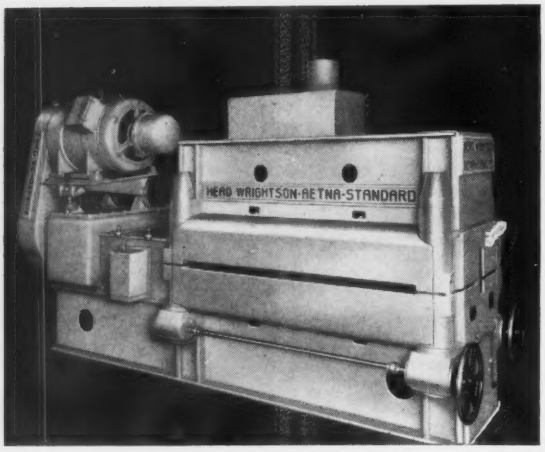
PIONEERS AND SPECIALISTS IN ELECTRICAL PRECIPITATION



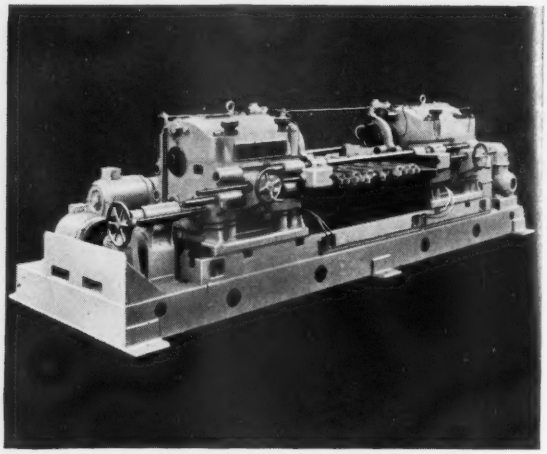
LODGE-COTTRELL LTD., GEORGE ST. PARADE, BIRMINGHAM. 3 *Telephone: CENtral 7714 (4 lines)*

4832

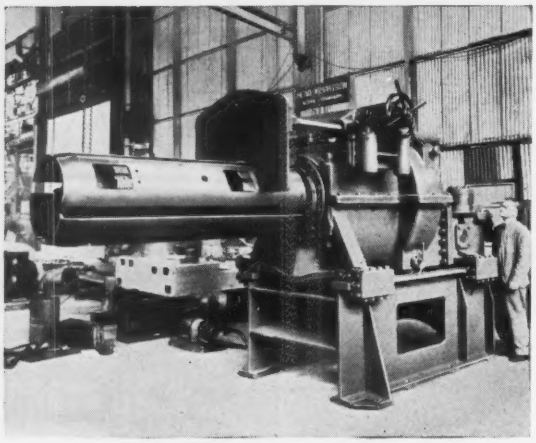
Head Wrightson Equipment for Plate, Sheet and Strip



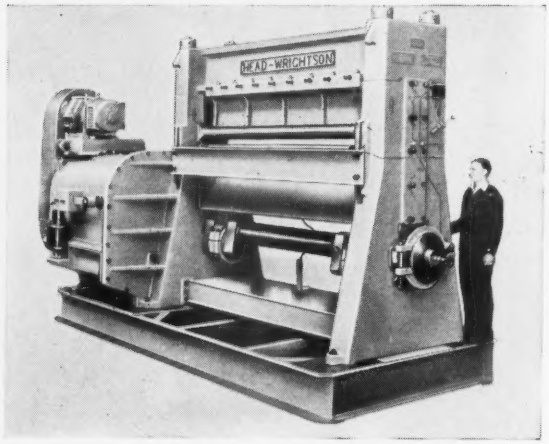
Roller and Stretcher Levellers



Edge Trimmers and Slitters



Coilers and Uncoilers



Resquaring and Upcut Shears

THE HEAD WRIGHTSON MACHINE Co. LTD.

Consultants, Designers and Builders to the Steel and Non-Ferrous Industries

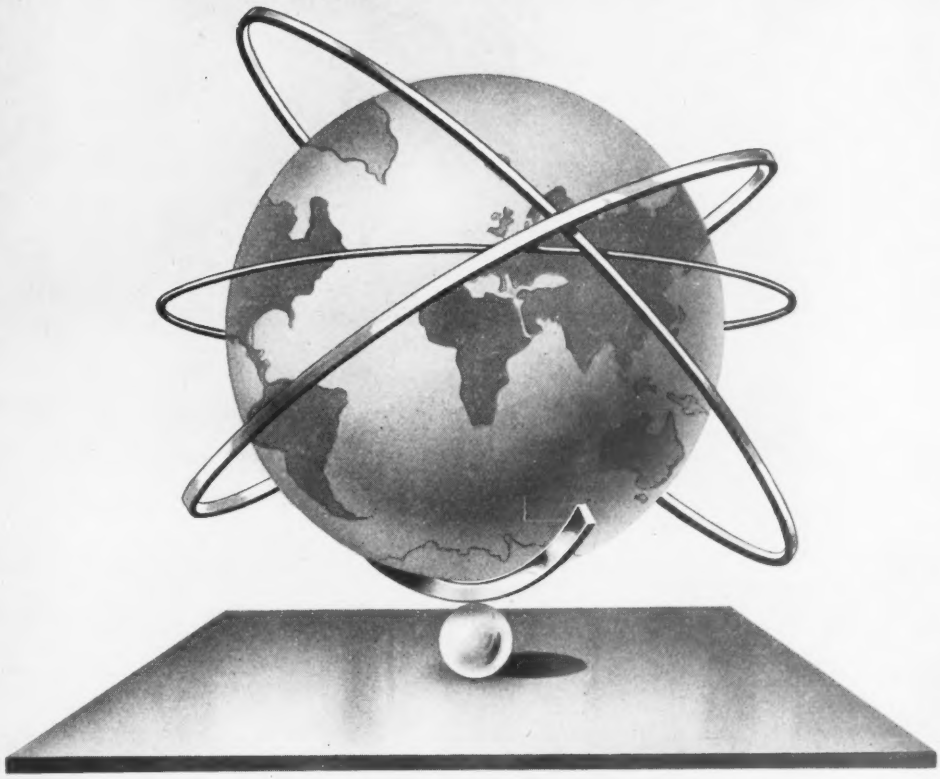
COMMERCIAL STREET, MIDDLESBROUGH

341-L

COLVILLES LTD

STEELS

ENCIRCLE THE GLOBE



WHERE OUR STEELS GO

EUROPE · BELGIUM · CYPRUS · DENMARK · EIRE · FAROE IS. · FINLAND · FRANCE · GIBRALTAR · GREECE · HOLLAND · ICELAND
ITALY · MALTA · NORWAY · PORTUGAL · SPAIN · SWEDEN · SWITZERLAND · YUGO-SLAVIA **ASIA** · ADEN · ARABIA · BORNEO
BURMA · CEYLON · CHINA · DUTCH EAST INDIES · HONG KONG · INDIA · IRAN · IRAQ · MAURITIUS · PAKISTAN · SEYCHELLES · SYRIA
AFRICA · EGYPT · GOLD COAST · KENYA · LIBYA · LIBERIA · NIGERIA · NYASSA · NORTHERN RHODESIA · SIERRA LEONE · SOUTH AFRICA
SOUTHERN RHODESIA · ST. HELENA · SUDAN · TANGANYIKA
NORTH AMERICA · BRITISH WEST INDIES · CANADA
DUTCH WEST INDIES · NEWFOUNDLAND
NICARAGUA · UNITED STATES OF AMERICA
SOUTH AMERICA · ARGENTINA · BRAZIL · BRITISH
GUIANA · CHILE · COLOMBIA · ECUADOR · PARAGUAY
PERU · URUGUAY · VENEZUELA
AUSTRALASIA · AUSTRALIA · FIJI ISLANDS · MALAYA
NEW ZEALAND · PENANG · SIAM · SINGAPORE · TONGA

COLVILLES LTD. 195 WEST GEORGE STREET GLASGOW C.2

We design to suit your particular operation...

This Multi-Chambered Forge Furnace was installed by us recently in the New Forge of Stavanger Electro-Staalverk A/S. It was designed for the controlled heating of a wide range of highly alloyed steel ingots of various sizes which have to be gradually raised from cold through successive critical temperatures to the final forging heat.

The plant consists of four primary and two secondary preheating chambers, two tertiary heating chambers and two final chambers for the reheating of semi-forged products. The furnace is oil fired and has full instrumentation. The doors are oil-hydraulically operated from a central control room.

WINCOTT FURNACES

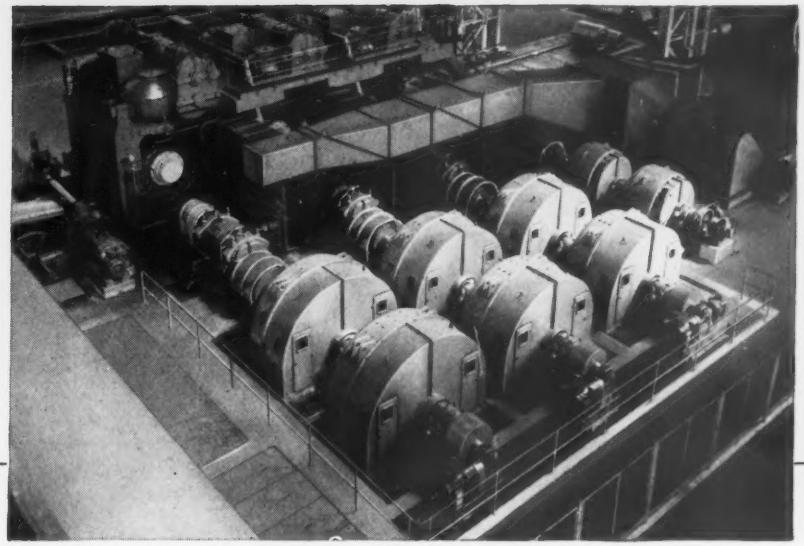
G.P. WINCOTT LIMITED SHEFFIELD, ENGLAND

Telegrams: WINCOTT, SHEFFIELD. *Telephone: 20211/2*

South African Representatives: Ashmore, Benson, Pease & Co. Africa (Pty) Ltd., 15, Simmonds Street, Johannesburg

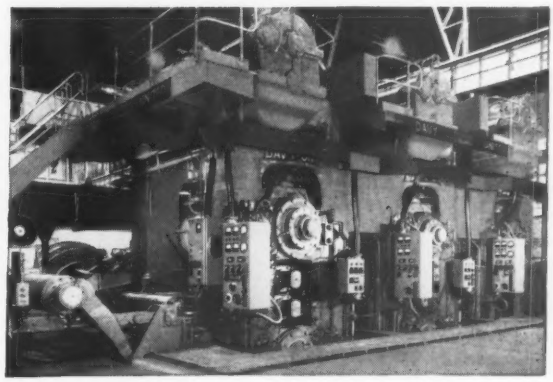
SBW/13

Main drives for cold tandem strip mills



'ENGLISH ELECTRIC' have supplied main drives for a number of cold tandem strip mills, such as the recently installed 3-stand Cold Reduction Mill (below) at the Steel Company of Wales' Abbey Works. This large mill handles strip up to 72" wide at speeds of up to 2,000 feet per minute and is driven by four direct-coupled motors (above) with a total R.M.S. rating of 13,000 H.P. The three motors for the stands are each 4,000 H.P., and the coiler motor is 1,000 H.P.

In the same works, the 9200 H.P. main drive for the 45" Slabbing Mill and a considerable amount of switchgear and fusegear of various types, are also the products of 'ENGLISH ELECTRIC' specialised experience.



'ENGLISH ELECTRIC'

rolling mill drives

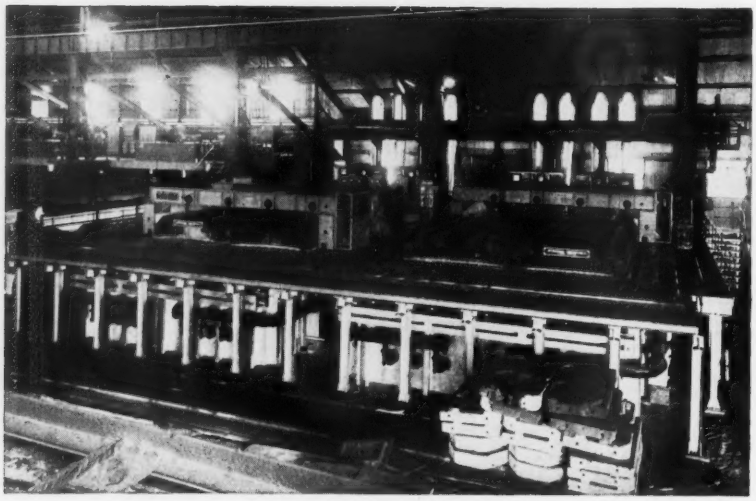
THE ENGLISH ELECTRIC COMPANY LIMITED, QUEENS HOUSE, KINGSWAY, LONDON, W.C.2

Metal Industries Division, Stafford

WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

MID. 12

ISLEY CONTROLLED



(1) 14-hole Soaking Pit Installation in South Wales fired with cold blast furnace gas and having accommodation for 140 four-ton ingots.

Repeat order-for 4-holes with fully automatic reversing control now in operation, making total capacity 180 four-ton ingots.

Further repeat order for 4-holes now in operation with complete fully automatic reversing equipment together with fully automatic air/gas ratio and draught control, and completely sealed covers, making a total holding capacity of 220 4-ton ingots.

(2) Installation in Cumberland accommodating 40 four-ton ingots and fired with blast furnace and coke oven gas having no pre-heat. Automatic gas/air ratio control.

(3) Installation in India with 16-holes fired with cold blast furnace gas and having automatic reversing control.

(4) Installation on N.E. Coast accommodating an average of 100 tons of slab ingots varying between 4 and 11 tons each, fired with 100 per cent. cold blast furnace gas, with fully automatic reversal.

(5) Installation on N.E. Coast accommodating 160 3½/4-ton ingots, fired with blast furnace gas and having fully automatic reversal equipment and air/gas ratio control.

(6) Installation in the Midlands of 4-hole plant accommodating 40 3/3½-ton ingots, fired with 100 per cent. cold blast furnace gas with automatic reversal equipment, gas/air ratio and furnace pressure control with completely sealed covers.

Repeat order for 2-hole plant to accommodate 24 3/3½-ton ingots with fully automatic reversing equipment and complete automatic air/gas ratio and draught control with completely sealed covers.

(7) Installation in South Africa of 8-holes with automatic reversal and fully automatic combustion control now under construction.

THE INTERNATIONAL

56 KINGSWAY, LONDON, W.C.2

SOAKING PIT FURNACES

★ PERFECTLY UNIFORM HEATING BOTTOM AND TOP OF INGOT.

★ EXTREMELY SIMPLE CONTROL.

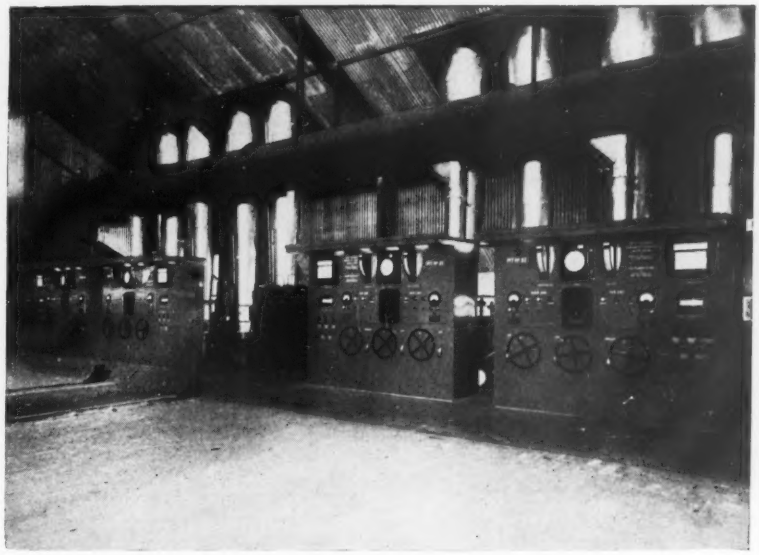
★ SUITABLE FOR FIRING WITH PRODUCER, BLAST FURNACE OR MIXED GAS.

★ ISLEY SOAKING PITS WILL HEAT COLD INGOTS TO OVER 1300° C. USING STRAIGHT BLAST FURNACE GAS WITH ABSOLUTELY NO PREHEAT OF GAS.

★ COMPLETELY SEALED COVERS.

★ AUTOMATIC GAS/AIR RATIO CONTROL AND AUTOMATIC FURNACE PRESSURE CONTROL.

★ FULLY AUTOMATIC REVERSAL GEAR.

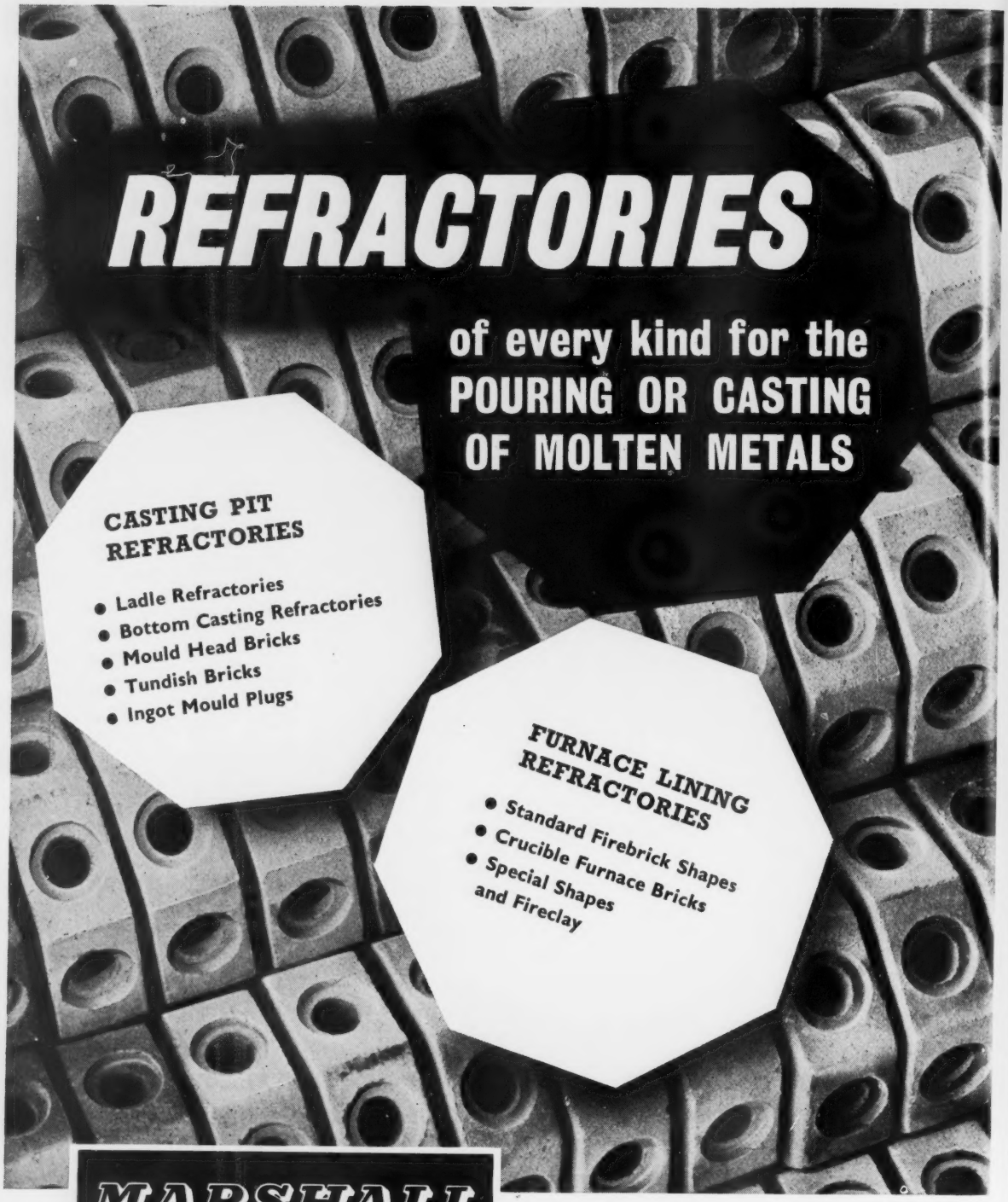


OTHER SPECIALITIES:

MORGAN GAS MACHINES • HOT METAL MIXER CARS • MORGAN CONTINUOUS ROLLING MILLS • TYPHOON ROTARY FLAME GAS BURNERS • MILL FURNACES • "ARCA" GAS PRESSURE REGULATORS • MORGAN AIRJECTORS

CONSTRUCTION CO. LTD.

Telephone: HOLBORN 1871/2 Telegrams: SAHLIN, WEST CENT 2 LONDON



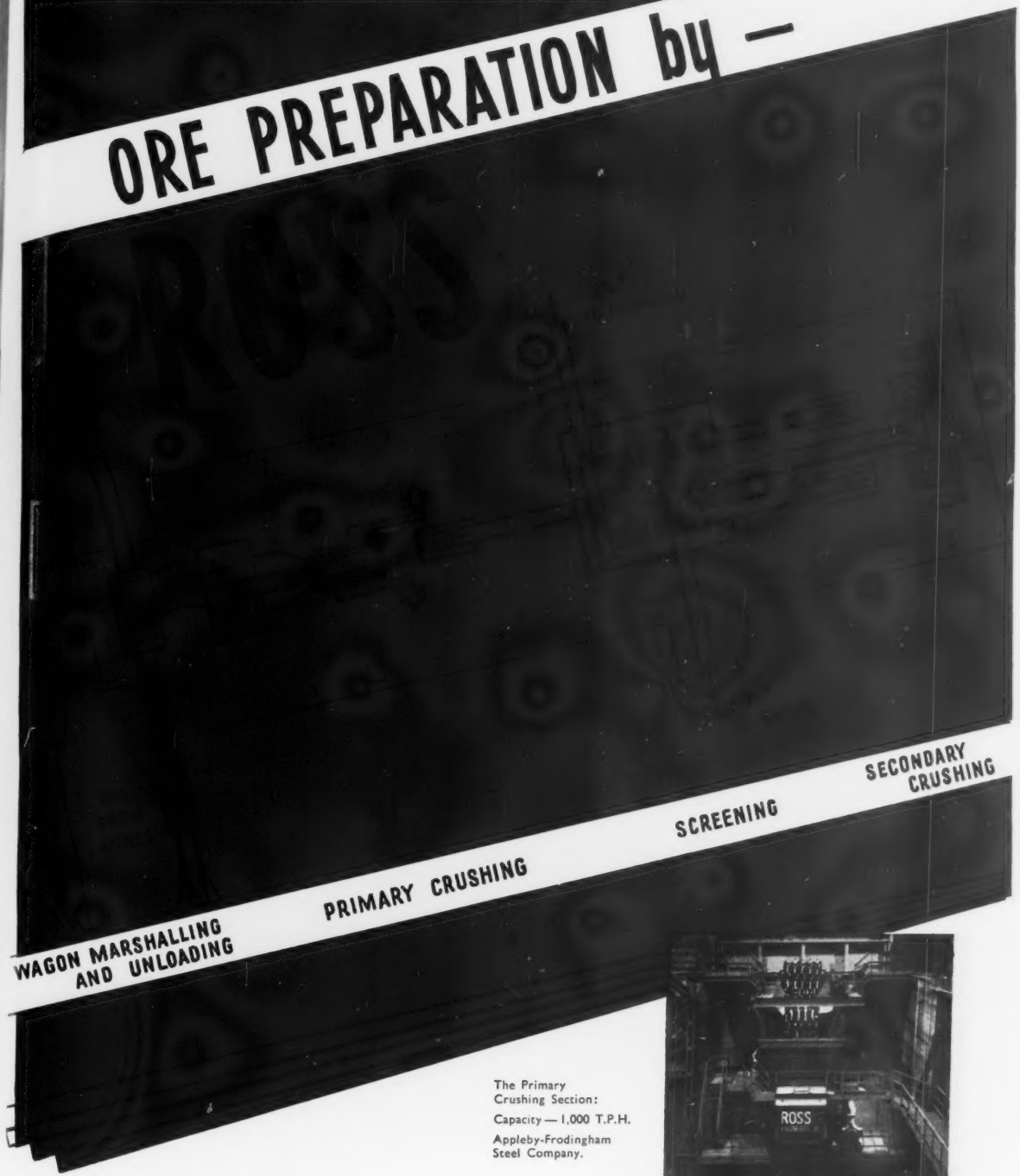
THOMAS MARSHALL & CO. (LOXLEY) LTD.

STORRS BRIDGE WORKS, LOXLEY, Nr. SHEFFIELD

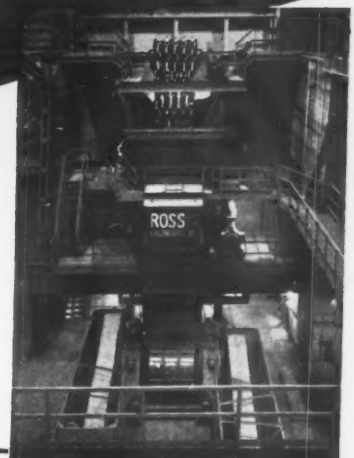
Telephone : Sheffield 43844/5/6 Telegrams : Marshall, Loxley, Sheffield

TM.24

ORE PREPARATION by —



The Primary Crushing Section:
Capacity — 1,000 T.P.H.
Appleby-Frodingham Steel Company.



ROSS ENGINEERS LTD., 11 WALPOLE RD., SURBITON, SURREY.
Tel: Elmbridge 2345
ROSS SCREEN & FEEDER CO., WESTFIELD, NEW JERSEY, U.S.A.

CI·C.15

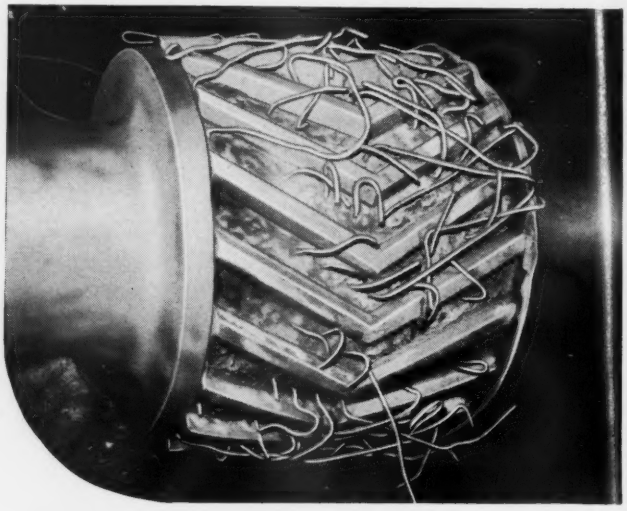
COMPLETE ORE PREPARATION PLANTS
PLANNING · DESIGN · CONSTRUCTION · COMMISSIONING

ROSS

B.O.C Powder Washing scours castings clean

Burnt-on sand, callouses, scabs and other blemishes are washed out of the trickiest corners—in one-tenth the time taken by pneumatic chipping

By this new method of fettling steel castings, burnt-on and metal penetrated sand, chill nails, flashing, etc., can be washed off in next to no time. Powder washing not only cleans the face, it washes behind the ears—getting right into the small corners and the deep pockets the chipping tool cannot reach. The photographs show a casting before and after Powder Washing. Long moulding wires protrude from recesses filled with burnt-on sand. With a Cutogen No. 7 Powder Washing Blowpipe, both sand and wires are washed away—doing a thorough job in one-tenth the time.

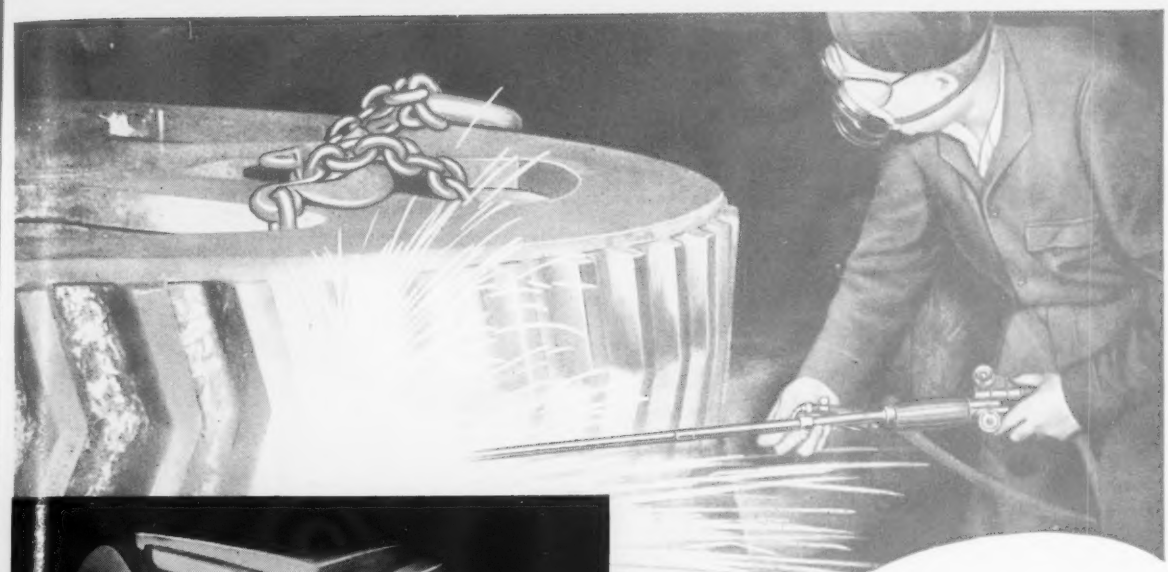


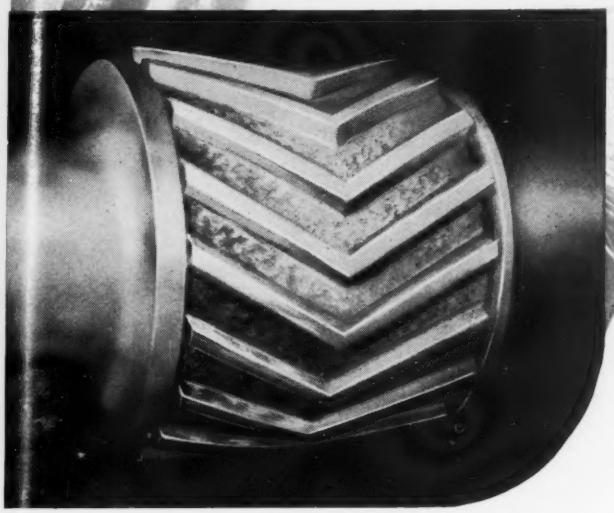
B.O.C Powder

Until the advent of Powder Cutting—and the BOC Cutogen Powder Cutting blowpipe—the only way of cutting and shaping stainless steel and nickel chrome alloys was the slow, laborious and costly mechanical method. Now these high-cost metals can be gas cut and shaped, profiled and bevelled as fast as low carbon steel.

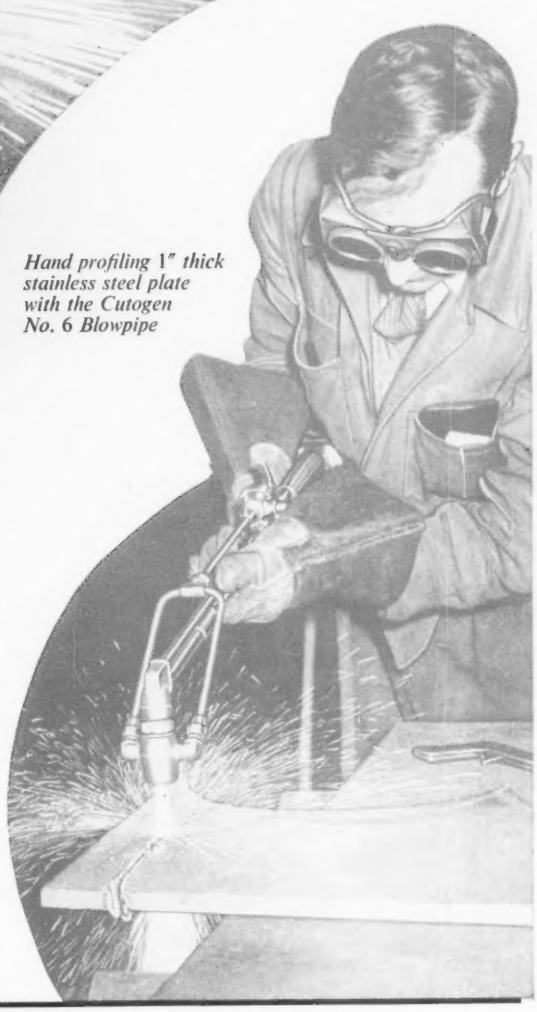
An example is pictured on the left: 5 in. thick ingots of high nickel chrome steel being trimmed to furnace size. The BOC Cutogen No. 6 Powder Cutting Blowpipe, taking the place of an abrasive wheel, does the job fast and does it well—at a great saving in cost.

These new processes could perhaps help you. Write for full details to your nearest BOC branch.





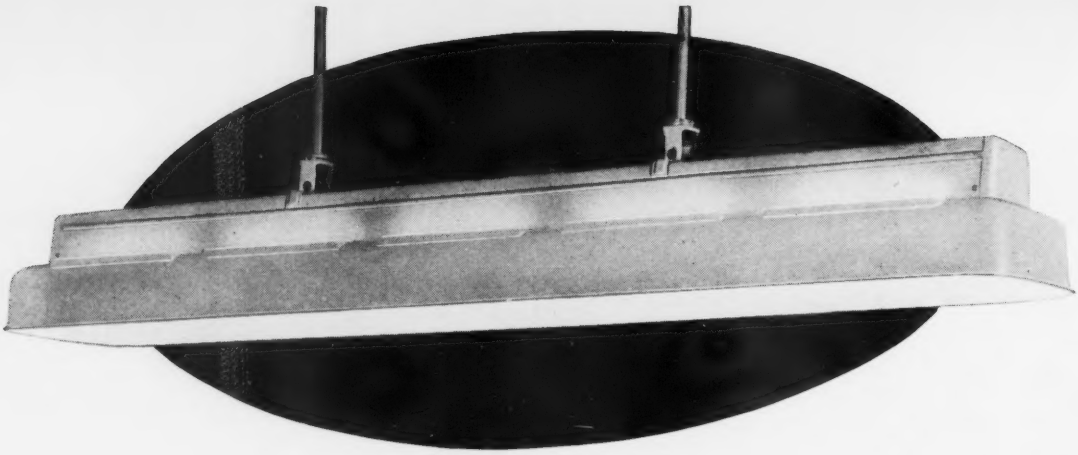
Hand profiling 1" thick stainless steel plate with the Cutogen No. 6 Blowpipe



Cutting severs stainless steel

At fast production speeds, Powder Cutting profiles, bevels or cuts thick stainless steel as easily as oxy-acetylene cuts mild steel

THE BRITISH OXYGEN CO LTD LONDON & BRANCHES



You'll be glad it's

There is a wide range of specially designed G.E.C. fluorescent fittings for every trade and industry. Simple to fit. Snap-action dismantling for quick, easy one-man maintenance. Consult your local contractor for best type of G.E.C. fitting . . . with of course Osram tubes.

G.E.C.

● *The General Electric Co Ltd, Magnet House, Kingsway, London WC2*

ROBERTSON

WIRE FLATTENING MILLS

1 A Four-High Single Stand Mill with work rolls 2¼" diameter, 4" face, and support rolls 6¼" diameter, 4" face.

2 A small Two-High Mill with rolls 4" diameter, 3" face.

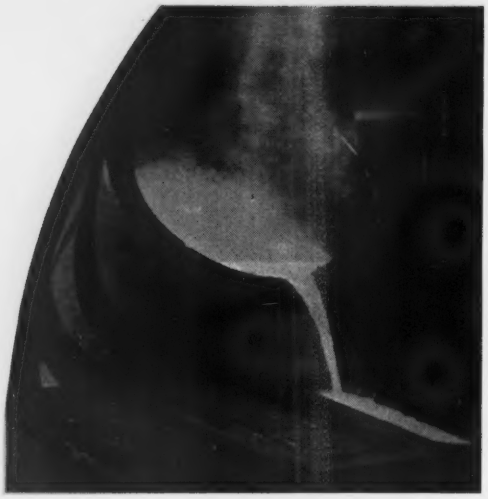
3 A Three-Stand Tandem, each stand individually motor driven and having rolls 6¼" diameter, 4" face.

4 A No. 2 Tormanco Tandem, with roughing rolls 10" diameter, 6" face, and finishing rolls 8" diameter, 6" face.

The examples illustrated above are from the range of Robertson Mills, which are designed for the production of square, rectangular or flat strip from round rod and wire in steel and all non-ferrous metals and alloys.

W. H. A. ROBERTSON & CO. LTD., BEDFORD

LICENSEES FOR THE BUILDING OF SENDZIMIR COLD REDUCTION MILLS & PLANETARY HOT MILLS



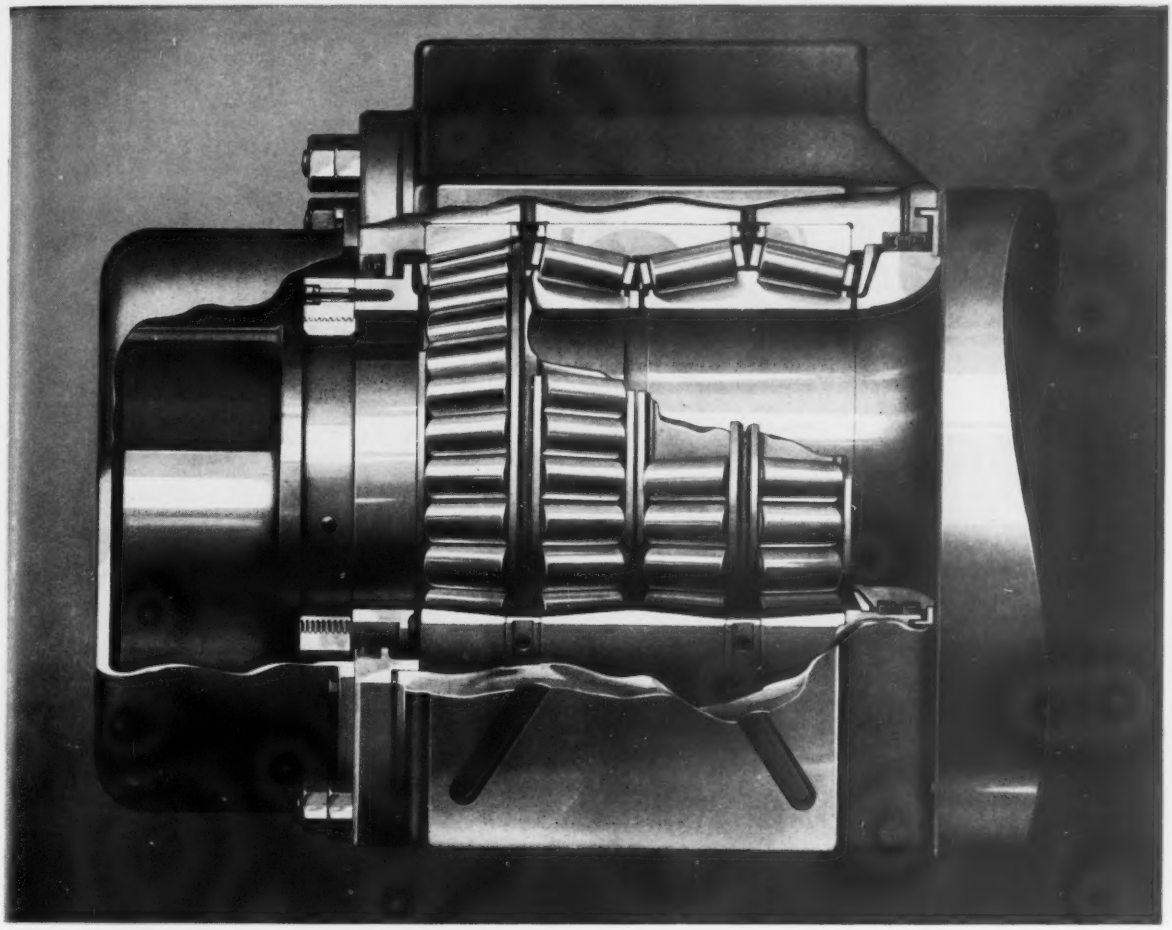
Making sure . .

Wise precautions always pay dividends. In Industry, as in Health, it pays to make sure—by not accepting a second-rate standard of casting metal, for instance. Take the precaution of CRUCIBLE melting. Then you will produce finer metal, with less rejects; you will have accurate temperature control for exact alloy specification, and better metallurgical conditions with reduced metal loss. Make sure, too, that it is

CRUCIBLE MELTING . . the Morgan way

THE MORGAN CRUCIBLE COMPANY LTD., BATTERSEA CHURCH ROAD, LONDON, S.W.11. BAT: 8822

F.26



FOR BIGGER ROLL-NECKS

Modern production imposes higher duties on rolling mills, with a resulting need for stiffer roll-necks. The illustration shows a bearing developed by Timken, of proportions so balanced as to provide a greater load capacity within a given volume. This means that we can provide, for mills in course of design, a bearing which will admit a considerably larger roll-neck, and yet have a greater load capacity and life expectancy.

The services of British Timken and their engineers are always at your disposal.

MADE IN ENGLAND

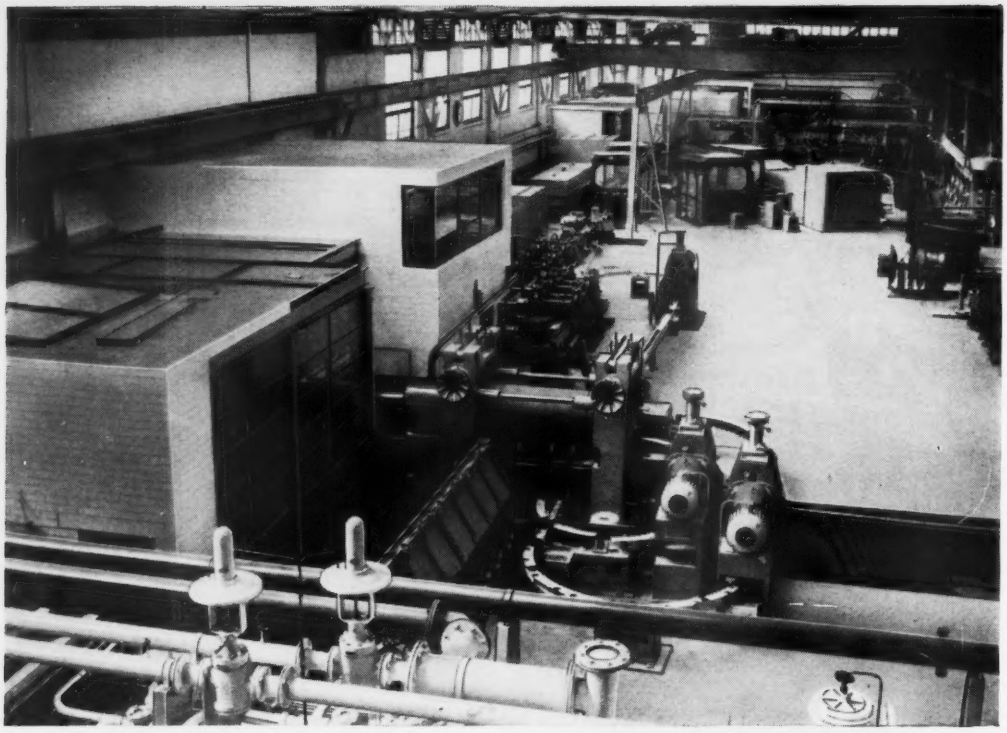
TIMKEN Regd. Trade Mark : TIMKEN

tapered-roller bearings

BRITISH TIMKEN LTD., DUSTON, NORTHAMPTON (Head Office); & BIRMINGHAM

Telephone : Northampton 4921/8 Telegrams : Britimken Phone Northampton

Subsidiary companies : FISCHER BEARINGS COMPANY Ltd., WOLVERHAMPTON, TIMKEN-FISCHER STOCKISTS Ltd., BIRMINGHAM



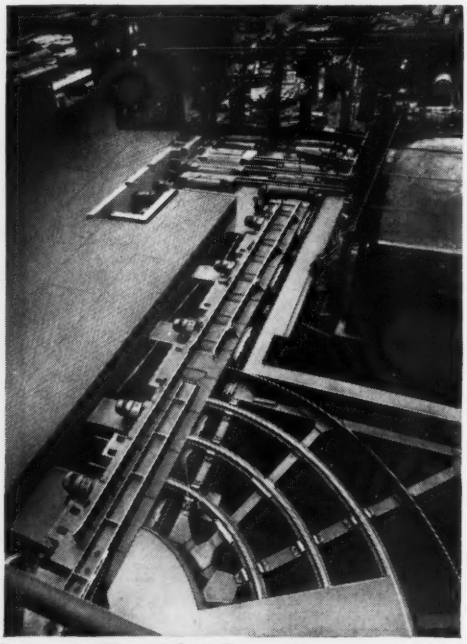
CONTINUOUS ROD MILL

Manufactured by B. THORNTON LIMITED for Messrs. Richard Johnson & Nephew Limited, to the design of their late Chief Engineer Mr. N. Philips Bedson, B.Sc., A.M.I.C.E., A.M.I.E.E.

ROTOR CYLINDERS

MACHINED ALL OVER AND BALANCED. Bore 5 ft. 6 in. Outside diameter 6 ft. 1½ in. Length overall of 3 cylinders assembled, 33 ft. 6¾ in. Weight 33 tons. By courtesy of Milshaugh Ltd., Sheffield.

ROLLER AND SKID GEAR FOR 12 IN. BAR MILL



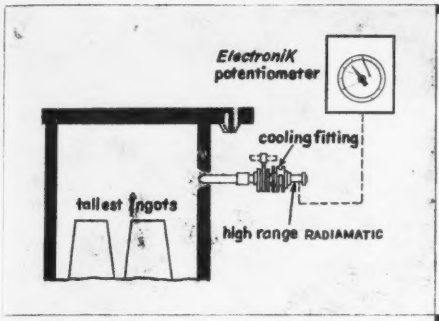
By courtesy of English Steel Corporation

B. THORNTON LIMITED

ENGINEERS CONTRACTORS

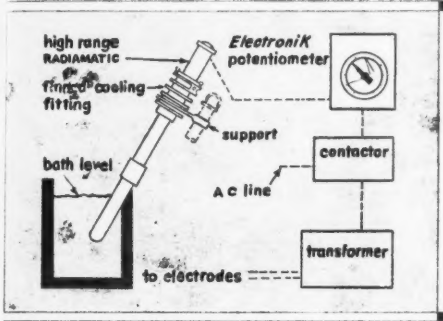
TURNBRIDGE, HUDDERSFIELD Telephone: Huddersfield 7541-2-3

typical applications of BROWN RADIAMATICS



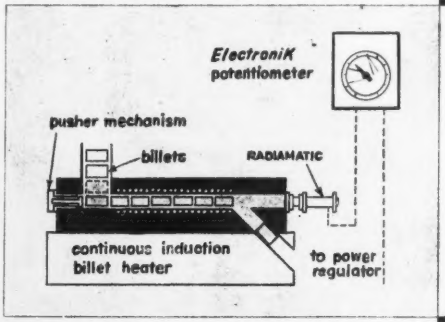
soaking pits

The Radiamatic may be used on either regenerative or recuperative soaking pits. For this service, the Radiamatic is sighted into a closed end sillimanite tube which is located so as to be responsive to the average temperature of the ingots. The Radiamatic, being unaffected by vibration and wide changes in the ambient temperature, is ideally suited for this severe service. Its high speed of response assures closer control.



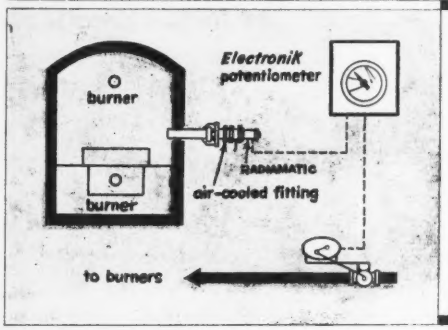
high speed salt baths

Automatic control of high-speed salt baths from a Radiamatic measurement assures the ultimate in close temperature regulation, thereby increasing the output of properly heat-treated work. A Radiamatic and closed end sillimanite target tube assembly is installed on an electrically heated salt bath. As shown in the illustration, the sillimanite target tube is immersed 4 to 6 inches into the bath and the Radiamatic sights on the closed end of the tube. A support fitting and adjustable clamp facilitate mounting the assembly, and the finned cooling fitting adequately protects the Radiamatic from overheating.



induction heating for forging

In induction heating for forging, the Brown Radiamatic is sighted on the work in direct line with the axis of the inductor coil of continuous billet heaters. Many factors, such as work speed, power input and frequency variations, determine work temperatures. Thus the Radiamatic, which provides the actual billet temperature, can be used with a temperature controller to actuate work speed, or power input regulators to obtain the desired billet temperature. The Radiamatic can also be used effectively with many other forms of induction heating where the target area and heating cycle permit.



forging furnaces

When used to measure forging furnace temperatures, the Brown Radiamatic is sighted into a closed end ceramic tube. The end of the tube is located so that a cold billet in the line will not unduly affect the temperature measurement, also so that the radiation it receives is principally from the walls of the furnaces and not from flame impingement. The Brown control system for forging furnaces consisting of Radiamatic, control instrument and motorized valves has numerous operating advantages.

Instrumentation data sheets available on request covering all applications of Brown Radiamatics.

Honeywell-Brown Ltd., 1 Wadsworth Road, Perivale, Greenford, Middlesex. *Sales Offices:* London · Glasgow · Birmingham · Manchester Sheffield · *Amsterdam · Brussels · Frankfurt/Main Paris · Stockholm · Zurich*

Honeywell

BROWN INSTRUMENTS

First in Controls

PRIEST

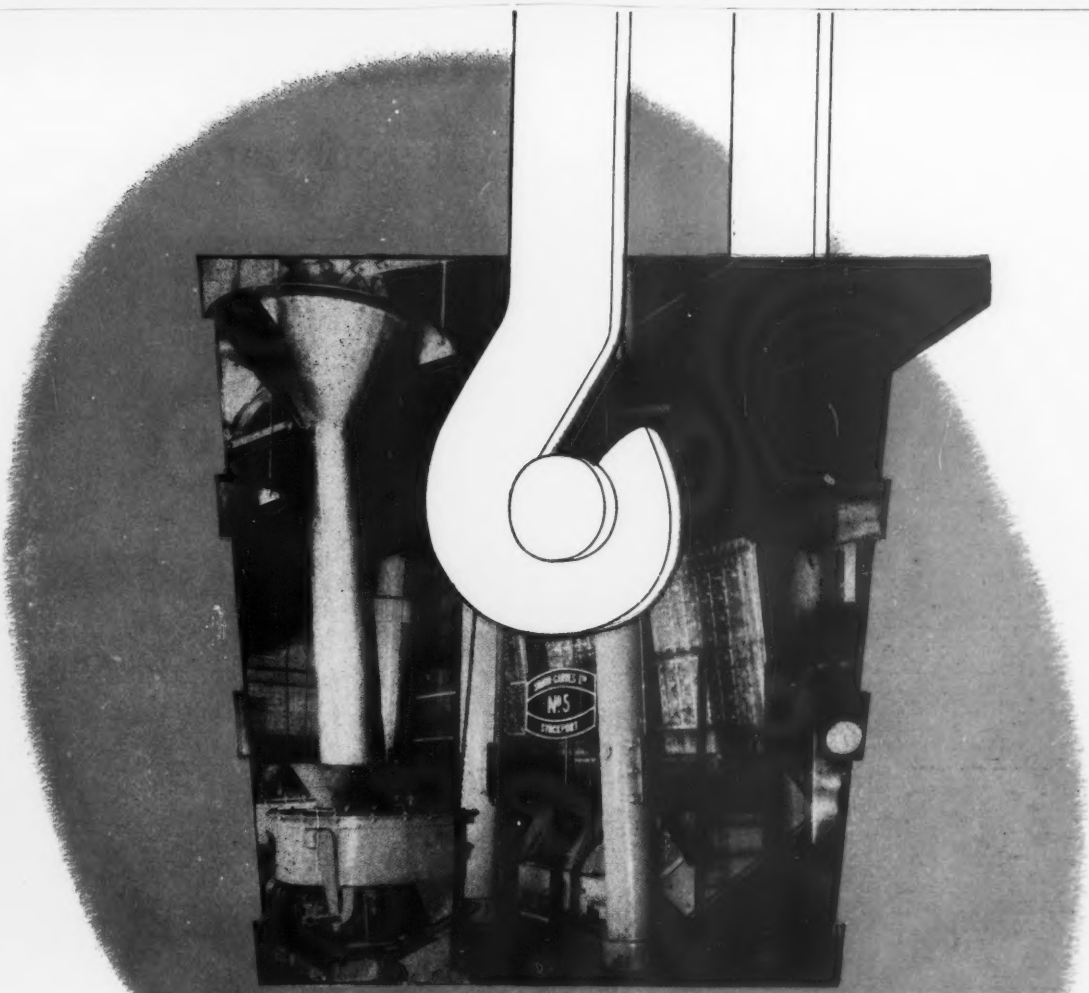
SOAKING PITS

Priest Soaking Pit installed for The Appleby-Frodingham Steel Company using blast furnace gas with air regeneration and gas recuperation.

PRIEST FURNACES LIMITED · LONGLANDS · MIDDLESBROUGH

also at TELEGRAPH BUILDINGS · HIGH ST SHEFFIELD

F.49



STEAM *and the making of steel*

The remarkable development in the steel production of this country since the war leaves no doubt of the virility of the British steel industry, and Simon-Carves are privileged to have taken part in the expansion. Their recently commissioned boiler installations at the Margam steelworks of the Steel Company of Wales and in the extension to the Simon-Carves boilerhouse at Richard Thomas & Baldwins, Ebbw Vale, exemplify the capacity of Simon-Carves to serve any industry requiring a reliable high pressure steam supply.

Steam power by Simon-Carves Ltd

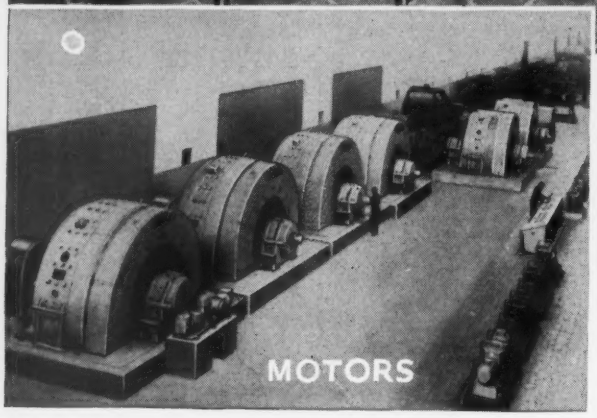
SIMON ENGINEERING GROUP

STOCKPORT, ENGLAND

OVERSEAS COMPANIES | *Simon-Carves (Africa) (Pty) Ltd: Johannesburg* *Simon-Carves (Australia) Pty Ltd: Sydney*

Rolling Mill Equipment

Pumpless Steel-tank Mercury-arc Rectifiers



BTH mercury-arc rectifiers have established themselves as an accepted type of electric current conversion apparatus for most applications. The main illustration shows a 21,000-kW, 800-volt, grid-controlled, mercury-arc rectifier equipment, comprising thirty pumpless, air-cooled, steel-tank, grid-controlled units giving 60-phase rectification. This equipment provides D.C. power for driving the finishing train of the hot strip mill in the Abbey Works of The Steel Company of Wales Ltd. The drive consists of six BTH D.C. motors totalling 28,000 h.p.

The services of BTH specialists in electric equipment for rolling mills are freely at the disposal of consulting and operating engineers.

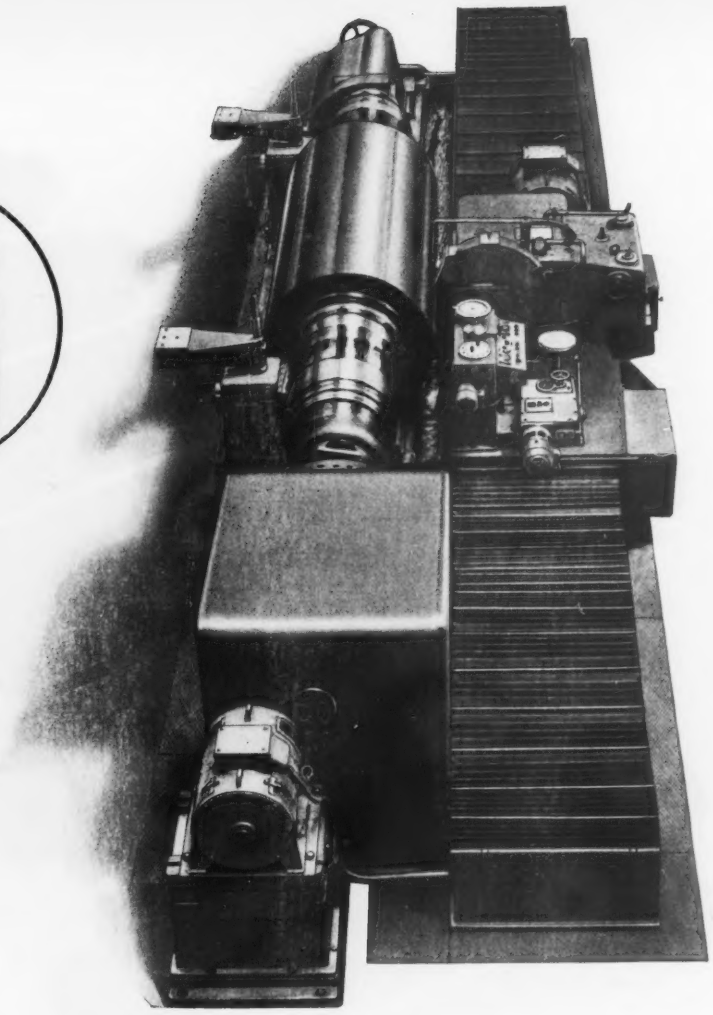
THE

BRITISH THOMSON-HOUSTON

COMPANY LIMITED, RUGBY, ENGLAND

Member of the AEI group of companies

A4373



Exclusive speciality

Roll Working Machines

Roll Roughing Lathes for cast and forged rolls
Roll Finishing Lathes for mills
Roll Ragging Machines and attachments
Roll Grinding Machines with travelling wheel
Roll Grinding Machines with travelling roll table
Roll Polishing Machines
Roll Wobbler Milling Machines

MASCHINENFABRIK HERKULES Siegen - Marienborn

Enquiries to:

BRITISH & CONTINENTAL TRADERS LIMITED

329 HIGH HOLBORN LONDON W.C.1.

THE IRON AND STEEL INSTITUTE

4 Grosvenor Gardens, London, S.W.1.

COUNCIL AND OFFICERS

PRESIDENT

The Hon. R. G. LYTTELTON

PRESIDENT-ELECT

Sir Charles BRUCE-GARDNER, Bt.

PAST-PRESIDENTS

The Rt. Hon. the Earl of DUDLEY, M.C.
Sir John CRAIG, C.B.E., D.L.
Arthur DORMAN
Cecil H. DESCH, D.Sc., Ph.D., F.R.S.
Sir Andrew McCANCE, D.Sc., F.R.S.
J. R. MENZIES-WILSON, O.B.E.
Richard MATHER
Capt. H. Leighton DAVIES, C.B.E.
James MITCHELL, C.B.E.

HON. TREASURER

William BARR

VICE-PRESIDENTS

Herbert Henry BURTON, C.B.E., D.Met.
Ian Frederick Lettsom ELLIOT
J. Sinclair KERR, M.Sc.
Gustavus Henry LATHAM
Neville H. ROLLASON
Gerald STEEL
Charles R. WHEELER, C.B.E.

HON. VICE-PRESIDENTS

Capt. C. A. ABLETT, O.B.E., B.Sc.
The Rt. Hon. Lord AIREDALE of GLEDHOW, D.S.O., M.C.
John Harold ANDREW, D.Sc.
William Beck BAXTER, C.B.E.
Carl A. F. BENEDICKS, Ph.D.
Alfonso de CHURRUCA
Wilfred John DAWSON, C.B.E.
Sir John DUNCANSON
Dr. Ing. Robert DURRER
Léon GREINER
Berndt Gustaf GRÖNBLOM
J. S. HOLLINGS, C.B.E.
Arnold H. INGEN HOUSZ
Sir John E. JAMES
Sir William LARKE, K.B.E.
Cyril E. LLOYD
Sir Arthur MATTHEWS, O.B.E.
Dr. Joseph OBEREGGER
Gunnar SCHJELDERUP
Evert WIJKANDER

MEMBERS OF COUNCIL

Harold BOOT
Donald Fraser CAMPBELL
William Frederick CARTWRIGHT
Richard Alan HACKING, O.B.E., M.Sc.
John Watson JENKIN, B.Sc., Ph.D.
George Henry JOHNSON
Thomas JOLLY
Edward Thomas JUDGE
Donald Arthur OLIVER, C.B.E., M.Sc.
Edward Julian PODE
Frank Henry SANITER
Charles SYKES, D.Sc., Ph.D., F.R.S.
B. Chetwynd TALBOT
Samuel THOMSON
Charles Harry Trelease WILLIAMS

HON. MEMBERS OF COUNCIL

Commercial Director, British Iron and Steel Federation — E. W. SENIOR
Director, British Iron and Steel Research Association — Sir Charles F. GOODEVE, O.B.E., D.Sc., F.R.S.
Chairman of the Engineering Committee — W. M. LARKE
President of the Cleveland Institution of Engineers — H. M. MORGAN
President of the Ebbw Vale Metallurgical Society — J. J. BEESE
President of the Institute of Metals — S. F. DOREY, C.B.E., D.Sc., F.R.S.
President of the Leeds Metallurgical Society — C. E. BURRELL
President of the Lincolnshire Iron and Steel Institute — Lt.-Com. G. W. WELLS, R.N. (Retd.)
President of the Liverpool Metallurgical Society — G. T. CALLIS, B.Sc.
President of the Manchester Metallurgical Society — J. D. HANNAH, M.Sc. (Tech.)
Chairman of the Newport and District Metallurgical Society — C. I. F. MACKAY
Chairman of the North Wales Metallurgical Society — E. TAYLOR-AUSTIN
President of the Sheffield Metallurgical Association — F. H. SANITER
President of the Sheffield Society of Engineers and Metallurgists — R. E. S. FISHER, M.C.
President of the Staffordshire Iron and Steel Institute — K. G. LEWIS, M.Sc., M.Sc.(Tech.)
President of the Swansea and District Metallurgical Society — H. O'NEILL, M.Met., D.Sc.
President of the West of Scotland Iron and Steel Institute — A. McKENDRICK, M.C.
Representatives of the Institution of Metallurgists — R. S. BROWN, M.B.E.
L. B. PFEIL, O.B.E., D.Sc., F.R.S.

SECRETARY

K. HEADLAM-MORLEY

ASSISTANT SECRETARY AND LIBRARIAN

A. E. CHATTIN, B.Sc.(Hons. Met.)

JOINT ASSISTANT SECRETARY

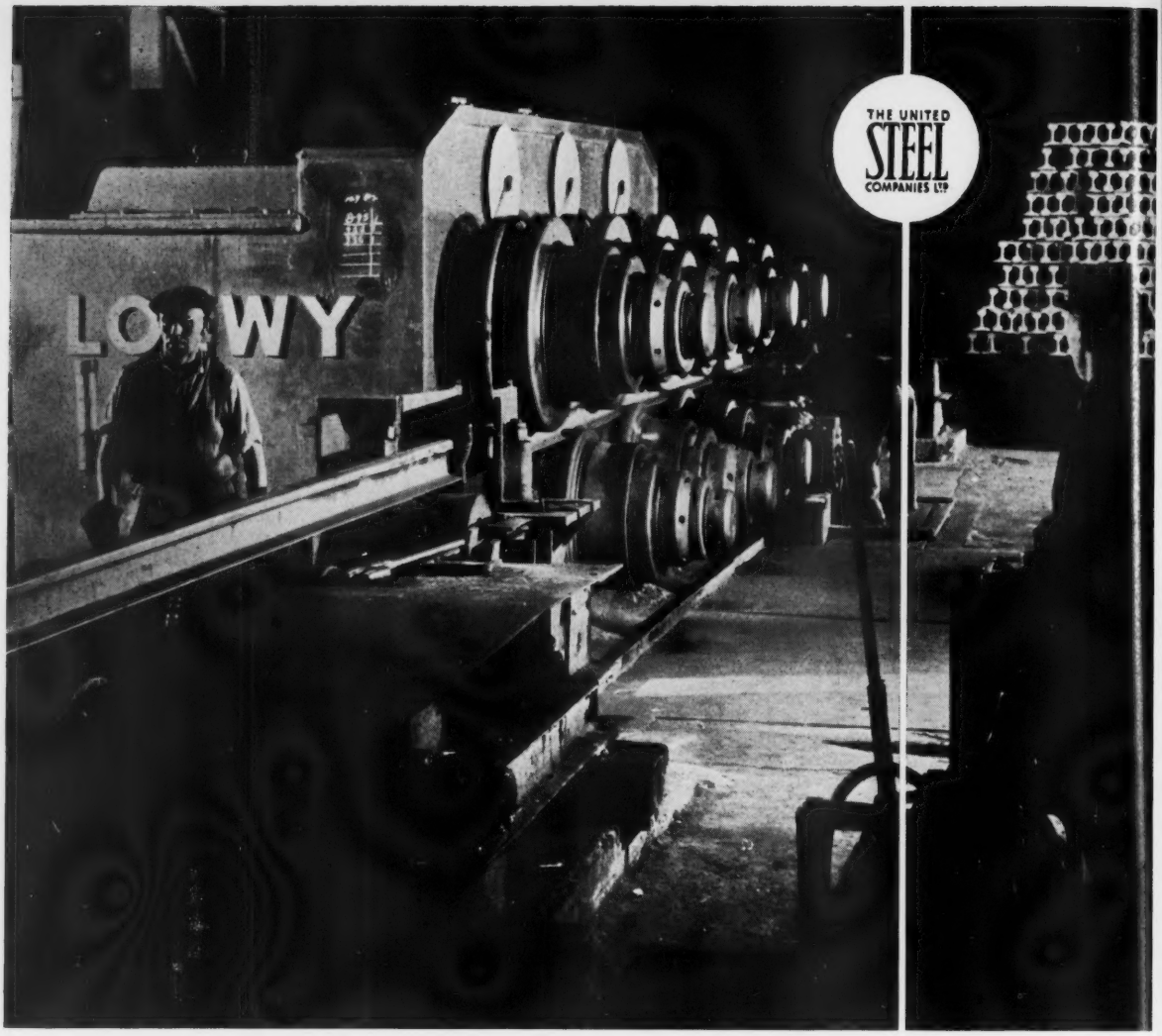
A. POST

JOINT SALES ORGANIZATIONS FOR FLAT-ROLLED MILD STEEL PRODUCTS

RTSC HOME SALES LTD and **RTSC EXPORTS LTD**

PARK STREET LONDON W1

Telephone MAYFAIR [illegible] *(Home Sales)* MAYFAIR [illegible] *(Export Sales)*



THE UNITED STEEL COMPANIES LIMITED of SHEFFIELD

The United Steel company employs over 30,000 workers and operates iron ore mines, limestone quarries, blast furnaces, iron foundries, steelworks forges, rolling mills and other ancillary plant. The products of the group serve the great consuming industries in mechanical engineering, shipbuilding, constructional and civil engineering, railways, the automobile and aircraft industries, hardware trades, indeed every activity which absorbs iron and steel products in their many forms.

APPLEBY-FRODINGHAM STEEL COMPANY SAMUEL FOX & COMPANY LIMITED STEEL PEECH & TOZER
UNITED COKE & CHEMICALS COMPANY LIMITED UNITED STRIP & BAR MILLS
UNITED STEEL STRUCTURAL COMPANY LIMITED WORKINGTON IRON & STEEL COMPANY

THE UNITED STEEL COMPANIES LIMITED, SHEFFIELD, ENGLAND

JOURNAL of THE IRON AND STEEL INSTITUTE

VOL. 178 PART 4

DECEMBER 1954

PUBLISHED MONTHLY

Editorial contents copyright by
THE IRON AND STEEL INSTITUTE

EDITOR
K. Headlam-Morley

MANAGING EDITOR
E. R. Mort, B.Sc., F.I.M.

TECHNICAL EDITOR
C. R. Harman, B.Sc. (Eng.)

PRODUCTION EDITOR
H. F. Cleere, B.A.

ASSISTANT EDITOR
Elizabeth S. Fairhurst

EDITORIAL AND ADVERTISEMENT OFFICES 4 Grosvenor Gardens, London, S.W.1 · SLOane 0061
Telegrams · · Irosamente, Sowest

SUBSCRIPTIONS
Members Free : Extra Copies 7s. 6d. each
Non-Members : £5. 0. 0 per annum
Single Copies 10s. each

NOTE
The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles, or discussion appearing in the Journal of The Iron and Steel Institute.

CONTENTS

THE IRON AND STEEL INSTITUTE

Some Aspects of the $\alpha \rightarrow \gamma$ Transformation of High-Purity Iron by P. R. Pallister 346

Thermodynamic Calculation of Slag Equilibria—II by K. Grjotheim 354

The Sulphur Distribution Reaction between Blast-Furnace Slag and Metal by J. Taylor and J. J. Stobo 360

DISCUSSION ON PAPERS

Discussion at Annual General Meeting, 1954 (Authors' Replies)—
Structure of Cast Irons 369
Rolling Mills 373

AFFILIATED LOCAL SOCIETIES

Use of Cold Coke-Oven Gas and Pitch-Creosote Firing on Tilting Furnaces. Development at Appleby-Frodingham by W. Jackson 378

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The Graphitization of Steel at Subcritical Temperatures by R. H. Hickley and A. G. Quarrell 337

Convection and the Heating of Scrap. A Theoretical Discussion by L. F. Daws and R. D. Collins 349

Absorptiometric Determination of Molybdenum in Iron and Steel by the Methods of Analysis Committee 356

LETTER TO THE EDITOR

Grain-Boundary Properties Effecting Cleavage Fracture by J. Short and A. Muscott 368

IRON AND STEEL ENGINEERS GROUP

High-Temperature Water Cooling of O.H. Furnaces by Steam-Producing Elements by F. J. Feltoe and P. M. Moreton 391

NEWS

The Iron and Steel Institute ... 396
News of Members 396
Contributors to the Journal ... 397
Iron and Steel Engineers Group 397
British Iron and Steel Research Association 397
Affiliated Local Societies ... 398
News of Science and Industry 398
Diary 399
Translation Service 399

ABSTRACTS

Contents 400
Abstracts 400–415
Book Notices 415–416
New Publications ... 416

THE IRON AND STEEL INSTITUTE, 4 GROSVENOR GARDENS, LONDON, S.W.1

A PRESS WITH A PEDIGR

DAVY-UNITED 6000 Tons FORGING PRESS at FIRTH-BROWNS

Costly capital equipment must guarantee its purchaser years of sustained production and top-quality service. This being so, there is obviously more future in buying equipment which has years of solid practical experience behind it and a background of continual design development intelligently adapted to changing conditions.

This particular forging press is one of the many which in the last three-quarters of a century have made forging on a "Davy" press a world-wide steelworks practice. Like most things of breeding its achievements are a little out of the ordinary. Capable of producing forgings from ingots of over 200 tons in weight, it has forged vital units for many of the most famous vessels ever launched, such as the Aquitania, the R.M.S. Queen Mary, R.M.S. Queen Elizabeth and R.M.S. Caronia for which all the boiler drums and propulsion shafting were formed between its tools.

(Crown Copyright Colour Photograph by P. G. Hennell, reproduced by courtesy of The Festival of Britain Office and Thos. Firth and John Brown Ltd., Sheffield.)

SHEFFIELD · MIDDLESBROUGH · GLASGOW
Builders of capital equipment for the metals and sugar industries of the world.

DAVY-UNITED

H. J. MILLER, M.Sc., F.I.M.

HERBERT J. MILLER was born in 1904. He was educated at Wolverhampton School and at the University of Birmingham, where he was awarded the degree of B.Sc. (Hons.) in 1925, and that of M.Sc. in 1926. In the same year he took up his first industrial appointment in the Research Laboratories of Kynoch Limited, Birmingham, a Company that was later merged with the Metals Division of Imperial Chemical Industries Limited. He remained with the latter until 1935, when he was appointed Senior Metallurgist to the newly-formed Copper Development Association.

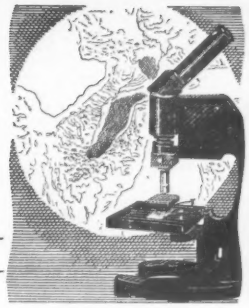
During the major part of the war, Mr. Miller was seconded to the Non-Ferrous Metals Control of the Ministry of Supply. Shortly after his release from the Ministry in 1945 he joined British Insulated Callender's Cables Limited; at present he holds the appointment of Engineering Manager of the Refinery and Mills Divisions of the Company.

Mr. Miller has taken part in the technical work of various non-ferrous metal trade research and other organizations. In 1951 he acted as leader of an O.E.E.C. mission to the U.S.A. concerned with the fabrication of heavy non-ferrous metals, the report of which has recently been published. A Fellow of the Institution of Metallurgists, Mr. Miller was President of the Liverpool Metallurgical Society for the Session 1953–54. He was elected a Member of The Iron and Steel Institute in 1954.

H. J. Miller, M.Sc., F.I.M.
Honorary Member of Council, 1953–54

PAPERS AND REPORTS ON RESEARCH AND PROGRESS

METALLURGY - PLANT OPERATIONS - RESEARCH



The Graphitization of Steel at Subcritical Temperatures

By R. H. Hickley, B.Met., Ph.D., and A. G. Quarrell, D.Sc., F.Inst.P., F.I.M.

SYNOPSIS

The nucleation and growth of graphite have been studied in a number of steels at 660° C. The previous history and chemical composition of the steel and the nature of the atmosphere in which it is heated are shown to have a profound effect upon the rate at which graphite is formed. An hypothesis based on the heterogeneous nucleation of graphite by γ-alumina and cristobalite formed during heat-treatment in atmospheres containing oxygen, is advanced to explain the experimental observations on steels initially containing metallic aluminium and silicon respectively. 989

THE cementite–graphite inversion in plain carbon steels at high subcritical temperatures is normally very slow but, particularly in aluminium-killed steels, it may be sufficiently rapid to cause premature service failure.[1]

An intensive investigation of subcritical graphitization has been carried out by Austin and his associates[2–7] who have studied 27 hyper-eutectoid steels. They obtained graphite in about half these steels in times of up to 600 hr. at 660°C., the temperature at which graphitization was most rapid. Graphite formed more rapidly in steels after quenching to martensite or cold-working than after normalizing or annealing. Austin postulated that rapid graphitization occurred because alumina in some form or dispersion provided nuclei on which graphite could form, but he stated that not all forms or dispersions of alumina could act in this way. Smith *et al.*[8, 9] on the other hand considered that graphite formation is accelerated because the aluminium ties up or 'scavenges' the nitrogen which otherwise stabilizes the cementite or inhibits its decomposition. In a paper published when the present work was nearing completion and had led to a similar view, Dennis[10] suggested that the potent form of alumina is formed during the subcritical anneal by internal oxidation of the metallic aluminium in the steel.

EXPERIMENTAL PROCEDURE AND RESULTS

In the first instance 15 plain carbon steels, whose analyses are given in Table I, were subcritically annealed *in vacuo* and examined for graphitization. Specimens 0·1 in. square × 1 in. long were austenitized for 1 hr. at 950°C. *in vacuo* and water-quenched to martensite before treatment *in vacuo* at 660 ± 1°C. for periods varying between 11 and 20 days; all heat-treatments were done in evacuated and sealed-off silica tubes of 0·25 in. bore. After this treatment only two of the steels had graphitized and these only to a small extent. Steels 2–6, which were from the same source and made by the same process, were then treated for 3 months using specimens pretreated as before, and cold-worked specimens reduced 80% in thickness by compression. The percentage graphitization of treated specimens was determined using a modification of the Eggertz method, in which the decarburized layer is machined off the specimen and a sample of about 0·2 g. is dissolved in cold dilute nitric acid (sp. gr. = 1·2), 0·1 c.c. being added per milligramme of specimen. The solution is heated on a boiling water bath for 10 min., cooled rapidly, and filtered. The absorption of the solution, measured with a Spekker photometric absorptiometer, gives the combined carbon content of the sample to an accuracy of ± 0·015% C, whence the graphite content is determined by difference.

The results are given in Table II. It is evident that as compared with the steels used by Austin *et al.* none of these steels was readily graphitizable. The only apparent difference between the two series of experiments is that the subcritical treatments in the present investigation were *in vacuo* whereas Austin used charcoal-covered lead baths. It seemed possible

Paper MG/A/159/52 of the Alloy Steels Committee of B.I.S.R.A., received 28th November, 1953. The views expressed are the authors' and are not necessarily endorsed by the Committee as a body.

Dr. Hickley is with the Mond Nickel Co., Ltd., Birmingham, and Dr. Quarrell is Professor of Physical Metallurgy in the University of Sheffield.

that the difference in rates of graphitization could be due to availability of oxygen, since lead has an appreciable solubility for oxygen at the temperatures used. Accordingly, quenched specimens of steels 3 and 6 were treated in lead at 660°C. for 20 days,* when steel 6 was graphitized to about the same extent as after 3 months' treatment *in vacuo* at 660°C. but from many more nuclei; steel 3 contained no graphite.

In view of these results the effect of oxygen under controlled conditions was investigated. Steels were treated at 660°C. in atmospheres of different constant partial pressures of oxygen by passing mixtures of dried air and dried commercial 'oxygen-free' nitrogen continuously over steel specimens supported on fused-silica racks in a tube furnace.

The oxygen content of the mixture was determined by means of flow meters and was adjusted and maintained constant by constant-pressure devices placed immediately before the flow meters. The partial pressures of oxygen employed were 0·2, 0·5, 7·1, 15·9, and 75 cm. respectively; the total pressure was always the prevailing atmospheric pressure. For the lowest partial pressure the total flow rate was 10 l./hr.; in all other experiments the rate was 5 l./hr. The maximum variations in partial pressure were ± 1·5% overnight and ± 2·5% over long periods.

The results obtained with steels 1, 4, 5, and 6 are given in Table III, and those for steel 3 in Fig. 1. All the steels had an as-quenched A.S.T.M. grain size of 6.

* The specimens used for this experiment and throughout the remainder of the work were of 0·175 in. dia. and 1 in. long.

Relationship between Graphitization and Time

A satisfactory relationship between graphitization and time may be developed by the analytical methods

Table I

CHEMICAL COMPOSITIONS OF THE STEELS INVESTIGATED

a. Main Series

Steel	Composition, %									
	C	Si	Metallic Al	Al_2O_3	Total Al*	Mn	S	P	Ni*	Cr*
1	0·93	0·10	0·034	0·005	0·05	0·30	0·014	0·030	0·01	0·20
2	0·53	0·13	...	...	...	0·36	...	...	0·04	0·10
3	0·62	0·06	0·031	0·017	<0·005	0·30	0·005	0·025	0·03	0·10
4	0·77	0·13	0·011	0·012	0·015	0·37	0·013	0·023	0·01	0·10
5	0·92	0·25	0·028	0·012	~0·1	0·31	0·018	0·024	0·01	0·03
6	1·26	0·26	0·034	0·007	0·04	0·36	0·013	0·022	0·01	0·10
A1	0·85	0·05	0·072 0·068	0·006 0·023	~0·1	0·10	0·023	0·015	0·05	0·05
A2	0·86	0·07	0·240 0·384	0·007 0·008	>0·1	0·10	0·022	0·015	0·05	0·05
A3	0·87	0·04	0·685 0·798	0·023 0·016	>0·1	0·20	0·021	0·013	0·05	0·05
A4	0·90	0·08	2·35 2·12	0·018 0·012	>0·1	0·20	0·025	0·014	0·05	0·05
S1	0·86	0·41	...	...	<0·005	0·20	0·025	0·014	0·05	0·05
S2	0·82	0·83	...	...	0·015	0·10	0·020	0·014	0·05	0·05
S3	0·85	1·64	...	...	0·015	0·10	0·028	0·014	0·05	0·05
PI	0·03	0·05	...	...	<0·01	0·15	0·009	0·020	0·05	0·05
PA	1·17	0·05	...	...	<0·01	0·20	...	...	0·05	0·05

*Other Elements**

Steel	Mo	W	V	Ti	Co	Cu	Zn	Sn	Pb
1	0·15	0·10	0·05	...	...	...	...	...	...
All others	<0·01	<0·02	<0·01	<0·02	<0·02	0·05	No indication	Slight indication	<0·05

b. Steels 7–15

Used for one experiment only and so full analyses were not made

Composition, %	Steel								
	7	8	9	10	11	12	13	14	15
C	0·88	1·00	0·98	1·21	0·70	0·89	0·62	0·61	0·94
Si	...	0·12	0·23	...	0·18	0·18	0·21	...	...
Mn	0·42	0·62	0·64	0·26	0·64	0·23	0·81	0·34	0·35

* Spectrographic figures

Table II

GRAPHITIZATION OF QUENCHED AND COLD-WORKED STEELS

After 3 months *in vacuo* at 660° C.

Steel	Carbon Content, %	Percentage of Graphite formed on Treatment at 660° C.	
		After Quenching	After Cold-working
2	0·53	33	0
3	0·62	91	0
4	0·77	0	0
5	0·92	94	39
6	1·26	95	90

used by Johnson and Mehl[11] and by Wert[12] for other transformations. Thus :

$$f(g) = 1 - \exp(-kt^n)$$

where $f(g)$ is the fraction graphitized, t is the time, and n and k are constants.

The validity of the relationship is illustrated in Fig. 2, where the regression lines were calculated from the results (joined by the full lines) in which graphitization was between 10 and 98%. Within these limits the percentage graphitization was determinable to within 2·5 and 1·5 units respectively for the steels containing 0·6 and 1·0% carbon. Figure 2 shows that the equation fits all the results for the steel which graphitized slowly. For the other two

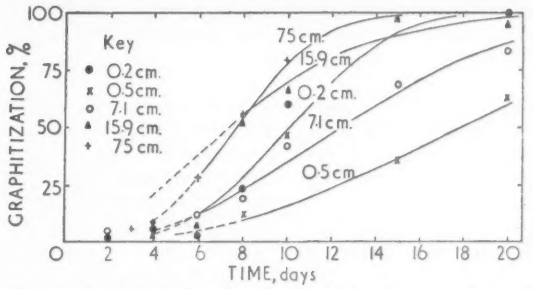


Fig. 1—Steel 3: Percentage graphitization *vs.* time of treatment at 660° C. for various constant partial pressures of oxygen

the fit is good only after about 30% graphitization.

In Fig. 1 the curves have been calculated from the results for steel 3 using the relationship given above. For this steel and for steels 4, 5, and 6 the rate of graphitization was at a minimum when the partial pressure of oxygen was 0·5 cm. Also, the more readily a steel graphitized the less was the effect of partial pressure of oxygen and the shorter the incubation period for graphitization. The rate of graphitization of steel 1, however, was not significantly affected by the partial pressure of oxygen in the surrounding atmosphere during treatment.

Effect of Surface Oxide on Graphitization

It seemed that the effect of different partial pressures of oxygen upon graphitization might be due to differences in the corresponding oxide scales

Table III

EFFECT OF PARTIAL PRESSURE OF OXYGEN ON GRAPHITIZATION

Austenitized at 950° C. and water-quenched

c = Complete graphitization

	Oxygen Pressure, cm.	Graphitization, %, after Time, days											
		⅓	½	1	1½	2	3	4	6	8	10	15	20
Steel 1 (0·93% C)	0·2	...	...	...	...	0	0	1	11	33	44	65	69 67
	0·5	...	...	0	...	1 1	0	0 7	5 0	35	43 46	60	70
	7·1	...	...	...	...	1 0	0 1	4	27	41	44	57	64
	15·9 (air)	...	...	0	...	0	0	1	0	40	49	63	67
	75·0 (O_2)	...	...	...	...	0	0	3	25	36	45	61	72
Steel 4 (0·77% C)	0·2	...	...	...	...	0	1	0	2	4	18	75	80 76
	0·5	...	...	...	...	0	3	0	3	5	15	70	35
	7·1	...	...	0	...	2	1	0	14	49	56	75	92
	15·9 (air)	...	...	...	...	0	4	8	23	45	35	93	99
	75·0 (O_2)	...	...	...	...	0	0	0	23	47	75	88	88
Steel 5 (0·92% C)	0·2	...	5	15	44	73	96	c	c	c	c	...	...
	0·5	...	8	29	66	83	86	95	c	c	c	...	...
	7·1	7	...	40	74	81	94	97	c	98	99	99	c
	15·9 (air)	...	7	34	72	71	88	97	99	c	c	...	...
	75·0 (O_2)	...	10	35	74	80	94	c	c	c	...	...	...
Steel 6 (1·26% C)	0·2	...	0	3	25	36	56	90	94	98	c	...	...
	0·5	...	1	2	12	21	31	61	89	97	c	c	...
	7·1	...	2	5	33	65	58	87	96	c	98	c	c
	15·9 (air)	...	3	8	40	11	71	87	94	96	c	...	c
	75·0 (O_2)	...	4	6	36	47	77	87	95	98	c	...	...

formed on the steel during subcritical annealing. Accordingly, the scales formed on steel 3 after treatment for 15 days at 660° C. in various partial pressures of oxygen were examined by the X-ray powder method. This steel was the most sensitive to changes in the partial pressure of oxygen. There was no apparent correlation between the nature of the scale and the tendency to graphitization. All the scales contained α- and γ-ferric oxides; ferrous oxide was found only in those formed in 0·5, 15·9, and 75 cm. partial pressure of oxygen.

Effects of Aluminium and of Silicon on Graphitization

The experiments on plain carbon steels revealed no significant correlation between the chemical composition of the steel and its tendency to graphitization. This could be accounted for if during treatment in oxygen foreign nuclei for graphite were formed, because large numbers of nuclei can arise from small amounts of nucleating substance. In fact, the faster rate of graphitization on treatment in oxygen was paralleled by increased nucleation of graphite.

Earlier work shows that aluminium is of importance

Table IV

EFFECT OF ALUMINIUM AND OF SILICON ON GRAPHITIZATION AT 660° C.

c = Complete graphitization

	Oxygen Pressure, cm.	Graphitization, %, after Time, days						
		¼	½	¾	⅞	1	1½	2
Steel *A1* (0·85% C, 0·07% Al*)	0·2	...	32	41	73	c	...	c
	0·5	...	7	25	86	93	c	97
	7·1	...	27	40	...	...	c	...
	15·9	...	14	44	...	85	c	c
	75	...	12	21	81	85	99	98
Steel *A2* (0·86% C, 0·31% Al*)	0·2	...	12	83	c	c	...	...
	0·5	...	14	58	80	c	...	...
	7·1	...	28	59	97	...	c	...
	15·9	...	...	...	...	...	...	...
	75	...	17	58	c	97	c	...
Steel *A3* (0·87% C, 0·74% Al*)	0·2	...	21	48	c	c	...	...
	0·5	...	14	49	94	c	...	...
	7·1†	...	16	50	94	...	...	c
	15·9	...	36	...	...	...	...	...
	75	...	62 64	47	c	91	c	...
Steel *A4* (0·90% C, 2·24% Al*)	0·2	...	c	c	...	...	...	...
	0·5	...	93	c	...	...	...	...
	7·1	...	c	c	...	...	...	...
	15·9	95	95	c	...	...	...	...
	75	99	99	...	...	...	...	...
Steel *S2* (0·82% C, 0·83% Si)	0·2	...	0	11	0	22	...	c
	0·5	...	0	2	5	16	63	94
	7·1	...	9	0	20	16	86	...
	15·9	...	21	12	16	40	c	86
	75	...	0	1	1	45	c	96
Steel *S3* (0·85% C, 1·64% Si)	0·2	...	2	82	98	c	...	...
	0·5	...	42	94	93	99	...	...
	7·1	...	25	c	c	...	...	...
	15·9	0	18	c	...	...	...	...
	75	4	24	c	...	c	...	...
Pure alloy *PA* (1·17% C, 0·01% Al,* 0·05% Si)	0·2	...	0	...	...	55	c	c
	0·5	...	0	15	...	53	87	98
	7·1	...	6	17	...	66	97	98
	15·9	...	1	23 12	27	87	c	c
	75	...	3	25	76	70	c	c

		6	8	10	15	20
Steel *S1* (0·86% C, 0·51% Si)	0·2	0	10	17	c	c
	0·5	0	0	10	16	45
	7·1	0	...	2	c	c
	15·9	0	0	3	c	84
	75	7	0	3	71	c

* Aluminium content is the content of metallic aluminium present in the steel.
† Treatment for ¼ day produced 22% graphitization.

in graphitization, so it was decided to test the effect of this element, present in solid solution in the ferrite, since this seemed the form most likely to give different results on treatment in oxygen from those obtained by treatment *in vacuo*. In view of the well-known effect of silicon upon graphite formation in cast iron, the effect of this element was also investigated. A pure iron–carbon alloy *PA* was included in these experiments; it was made by saturating austenite with carbon at 940° C. by soaking 0·2-in. dia. pure iron rods in a hydrogen–methane atmosphere.[13]

Fifteen-pound ingots of seven steels were made in a small high-frequency induction furnace, cropped, and hot-rolled to ¼-in. dia. bar. They were deoxidized with aluminium or silicon to give the residual alloy contents quoted for steels *A*1–*A*4 and *S*1–*S*3 in Table I. Quenched specimens (as-quenched A.S.T.M. grain size of 6) were treated at 660° C. in the partial pressures of oxygen used for the plain carbon steels with the results given in Table IV.

The absorptiometric method for the determination of combined carbon could not be used for the alloy steels because, when present in such large amounts, the alloying elements were found to interfere with the formation of the coloured compound. Graphite was therefore separated from the treated specimens and estimated by the usual combustion method. This method was neither so convenient nor so accurate as the absorptiometric method when used for the small samples of the present work; it enables graphite to be determined to ± 0·03%.

The results show that in quantities of the order of 0·1%, aluminium is much more potent than silicon in promoting graphitization but, for concentrations of about 1·0%, aluminium is only about three times more effective than silicon.

As with the plain carbon steels, the greater the rate of graphitization the more numerous are the nuclei revealed metallographically and the lower is the sensitivity to the partial pressure of oxygen in the surrounding atmosphere during heat-treatment. Moreover, when quenched specimens of the pure iron–carbon alloy and of the aluminium and silicon steels were treated *in vacuo* at 660° C. for times which gave complete graphitization on treatment in air, only three contained graphite. Steels *A*2 and *A*3 each contained a few graphite particles, whilst steel *A*4 although completely graphitized contained fewer nuclei than the corresponding specimen treated in air.

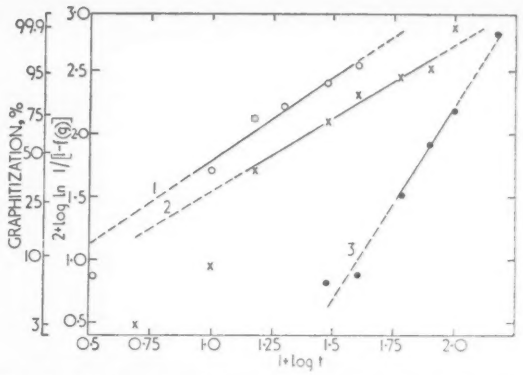


Fig. 2—Relationship between graphitization and time for: (1) Steel 5 at 7 cm. partial pressure of oxygen; (2) steel 6 at 16 cm. partial pressure of oxygen; (3) steel 3 at 75 cm. partial pressure of oxygen

Effect of Cold-Working and of Full Annealing upon Graphitization

Cold-worked specimens of steels 5, *A*4, and *S*3, the most easily graphitized members of their respective groups, were produced by wire-drawing to 45% reduction in area after patenting at 480° C. Fully annealed specimens were austenitized to give an A.S.T.M. austenite grain size of 6 before furnace cooling. Treatments at 660° C. in a stream of dried air gave the results in Fig. 3 (steel *A*4) and Table V (steels 5 and *S*3).

The results are typified by Fig. 3 and support the conclusions of earlier workers that graphitization occurs more readily in quenched or cold-worked steels than in fully annealed steels. Under the conditions of

Table V

EFFECT OF COLD-WORK AND OF FULL ANNEALING ON GRAPHITIZATION

c = Complete graphitization

Pretreatment	Duration of Subcritical Anneal	Graphitization, %
Steel S3		
Cold-worked 45% reduction in area	3 hr.	0
	6 ,,	0
	12 ,,	65
	27 ,,	c
Annealed	3 days	0
	6 ,,	48
	10 ,,	98
Steel 5		
Cold-worked 45% reduction in area	3 ,,	0
	6 ,,	20
	10 ,,	65
	20 ,,	99
Annealed	20 ,,	0

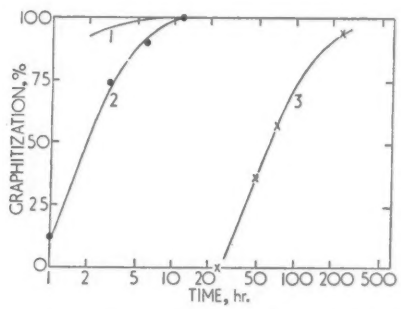


Fig. 3—Effect of pretreatment on graphitization at 660° C. (steel *A*4): (1) Previously quenched to martensite; (2) previously cold-drawn (45% reduction of area); (3) previously fully annealed

these experiments, graphitization occurs more readily after quenching than after cold-working.

Metallographic Examination of Graphitized Specimens

Typical structures observed in treated specimens are illustrated in Figs. 4–6. In the first stages of graphitization (Fig. 4), the cementite particles apparently do not break down directly to graphite *in situ*. The graphite is almost completely surrounding some of the cementite particles and after longer periods of treatment the larger graphite areas were observed to include several particles, believed to be cementite. Figures 5*a–c* show specimens of steel *S*3 (0·85% C, 1·64% Si) which had been subjected to different pretreatments and then completely graphitized in dry air; the effect of the pretreatment upon the numbers of effective nuclei is apparent. Growth of the graphite particles in partially graphitized specimens leads to progressive dissolution of the cementite particles in the adjacent region, an effect shown in Fig. 6.

In all the specimens which were not completely graphitized, graphite particles were seen only at ferrite grain boundaries, as reported by Dennis.[10] In completely graphitized specimens graphite particles were often seen remote from the ferrite grain boundaries, presumably because the ferrite grains had grown after all the cementite had disappeared.

Rate of Nucleation and Growth of Graphite

To study the nucleation and growth of graphite the numbers and sizes of the particles present in specimens treated for different times were determined using a method due to Scheil.[14] The number of patches in which particles intersect a plane of the specimen are counted and sorted into size ranges according to their diameters. The number and size distribution of the particles are then calculated from the plane distribution data.

In the first stages of graphite formation the particles are not spheres, but when they have grown to about 5×10^{-4} cm. in diameter they approximate to spheres sufficiently closely for Scheil's method to be used; accordingly, the present determinations only include particles of diameter 5×10^{-4} cm. or greater. Since Scheil's method is statistical it can only be applied satisfactorily when the number of particles is sufficiently large. Therefore, if the rate of nucleation is too fast or too slow, graphitization cannot be adequately followed metallographically.

An added complication is that with specimens treated in the presence of oxygen the graphite nucleation varies with the distance from the surface of the specimen, as shown in Fig. 7. Accordingly, the fields examined were always half way between the outside and centre of the specimen. For each specimen four fields on diameters mutually at right-angles were studied at a magnification of × 285 diameters; the field image was the size of a half-plate.

The numbers and size distributions of graphite particles were determined for the following series of specimens previously treated and analysed for graphite:

Steel 3 (0·62% C) at 0·2 and 0·5 cm. of oxygen
Steel 5 (0·92% C) at 0·5 cm. of oxygen
Steel 6 (1·26% C) at 0·2, 0·5, and 15·9 cm. of oxygen.

The six series covered a range of rates of graphitization, but only that for the hyper-eutectoid steel 6 treated at 0·5 cm. of oxygen enabled the growth of graphite to be followed over a wide range of percentage graphitization. The results for steels that graphitized more slowly showed considerable scatter because insufficient particles were present, whereas for steels which graphitized more quickly only the later stages of the process could be followed since by the time the particles had reached the measurable size graphitization was far advanced.

The growth and nucleation curves for steel 6 treated at 0·5 cm. partial pressure of oxygen are plotted in Figs. 8 and 9. The slope of the line in Fig. 8 is 0·5; this is the value to be expected from the equation deduced by Zener[15] for the growth of a spherical particle precipitated from a binary solid solution. Zener showed that under these conditions the radius r of the particle at time t should be given by $r = at^{\frac{1}{2}}$, where a is a constant.

The 'group average radius' quoted in these diagrams is the average radius, determined graphically, of a constant number of the largest particles present. This quantity was used in preference to the more usual 'largest patch radius' because the method based on the latter assumes that a particle of the largest size present is cut across an equatorial plane. This is by no means certain for the slowly graphitized steels.

Number of Graphite Particles in Completely Graphitized Specimens

In completely graphitized specimens most of the particles are approximately spherical and the total number present can therefore be determined. The numbers and size distributions of the graphite particles present in all the steels after complete graphitization in dry air were evaluated. The measurements were made at magnifications varying from × 200 to × 1600 according to the size range of the particles present. Where the patches were not circular the diameters of circles equal in area were estimated and used in the subsequent calculations.

Figure 10 shows that, in general, the faster the graphitization the more numerous the nuclei, but the relationship varies with the type of steel; furthermore, nucleation is markedly affected by the pretreatment given to the steel (*cf.* Figs. 5*a–c*).

Approximate Rate of Growth of Graphite

An approximate method for the determination of growth rate has been devised which is not subject to the limitations of the previous method and can be applied to any steel provided the number of nuclei in the completely graphitized specimen is known. In applying this approximate method it is assumed that :

(i) The largest visible patch arises from the cutting along a diameter of a particle nucleated at the beginning of graphitization
(ii) The particles giving rise to the largest patches have grown for only half the time required for complete graphitization.

The first assumption is questionable for the slowly graphitized steels. As shown in the Appendix, the second assumption is justified, provided that the rate

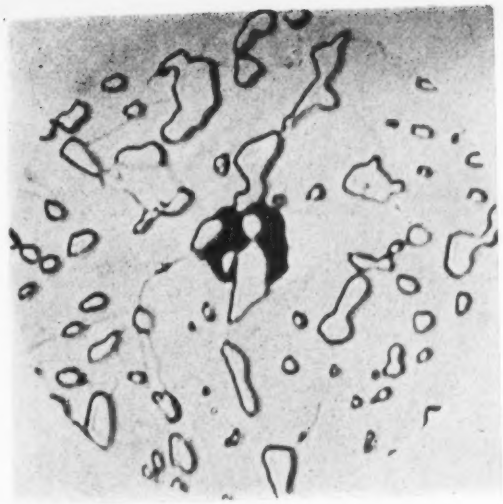
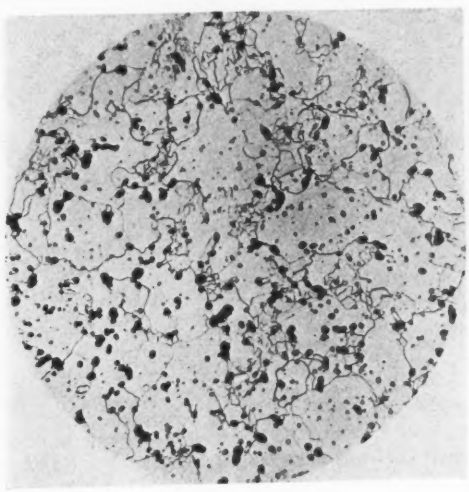
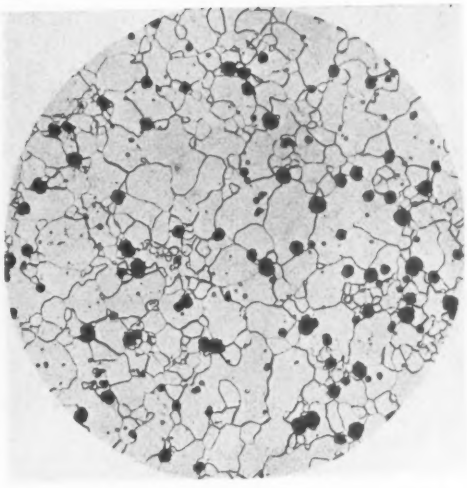


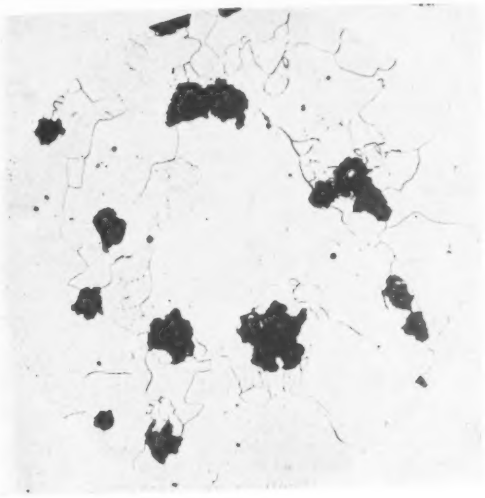
Fig. 4—First stages of graphitization × 2450



(a)



(b)



(c)

Fig. 5—Effect of previous treatment on graphite nucleation. Steel *S3* (1·64% Si) completely graphitized at 660° C. at 16 cm. partial pressure of oxygen (dried air): (*a*) Previously quenched to martensite; (*b*) previously cold-drawn (46·5% reduction of area); (*c*) previously fully annealed. Etched in Vilella's reagent × 150

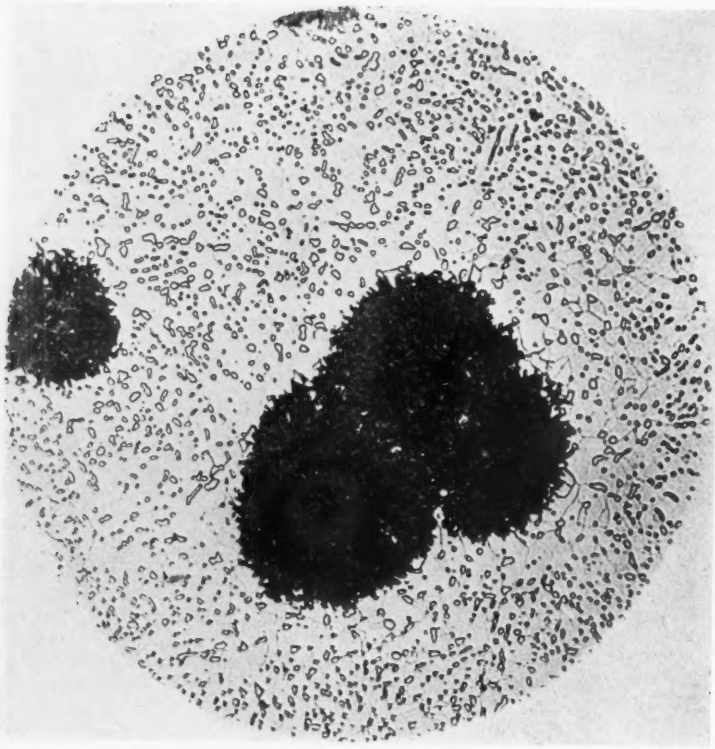


Fig. 6—Partially graphitized specimen showing preferential solution of cementite near graphite particles × 1225

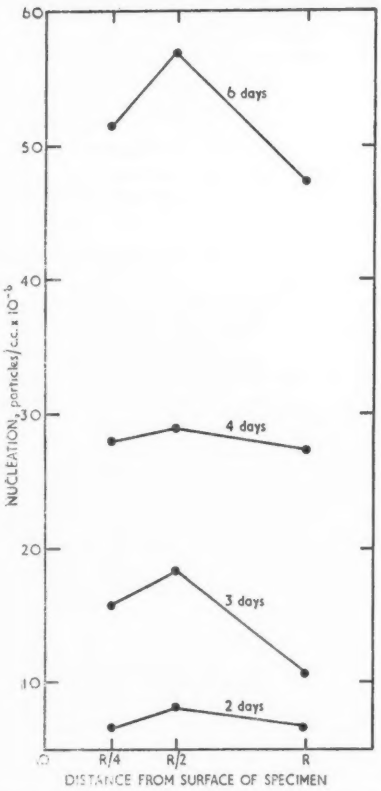


Fig. 7—Variation in nucleation with distance from the surface of the specimen: steel 6, quenched to martensite, treated at 660° C. at 0·5 cm. partial pressure of oxygen

of nucleation is constant to 50% graphitization and Zener's equation is applicable to the growth of graphite. It was found that both these conditions were satisfied in the one series of experiments which allowed the rates of nucleation and of growth to be determined over a wide range of percentage graphitization.

Then substitution of r, the maximum particle radius at complete graphitization, and t, the half-time for complete graphitization, in Zener's equation, enables the calculation of the constant a which is an index of growth rate.

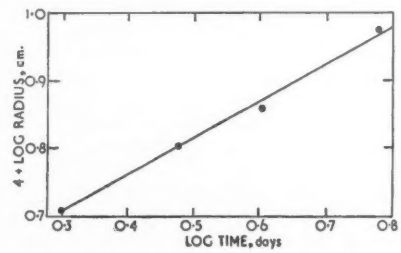


Fig. 8—Growth curve for steel 6, quenched to martensite, treated at 660° C. at 0·5 cm. partial pressure of oxygen

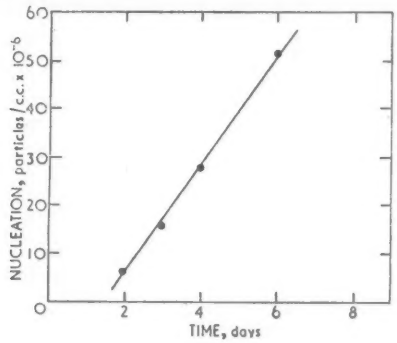


Fig. 9—Nucleation curve for steel 6, quenched to martensite, treated at 660° C. at 0·5 cm. partial pressure of oxygen

The results, quoted in Table VI, show that the rate of growth of graphite tends to be highest for the silicon steels, lowest for the plain carbon steels, and intermediate for the aluminium steels and the iron–carbon alloy. The growth constant calculated from the results given in Fig. 8 is $1{\cdot}5 \times 10^{-6}$ cm./sec.$^{\frac{1}{2}}$ and the approximate method leads to the same value.

From this result it can be shown, following the ideas of Zener,[15] that the difference between the limits of the α ranges of the iron–cementite and iron–graphite diagrams at 660°C. is very small—less than 5×10^{-5} wt.-% C.

DISCUSSION

For all the 15 steels examined in detail, treatment in the presence of oxygen caused subcritical graphitization to occur much more rapidly and from many more nuclei than treatment *in vacuo*. Seven other steels were treated *in vacuo* only, and these also did not graphitize readily. These observations are in keeping with the view that homogeneous nucleation is slow and that treatment in oxygen leads to the formation within the steel of foreign particles capable of nucleating graphite. Such foreign particles might be formed by internal oxidation, the oxygen diffusing into the steel and oxidizing certain alloying or

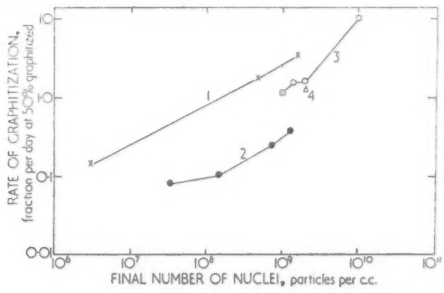


Fig. 10—Rate of graphitization at 50% graphitized state *vs.* final concentration of nuclei. Steels quenched to martensite, completely graphitized at 660° C. at 16 cm. partial pressure of oxygen (dried air): (1) High-carbon silicon steels; (2) plain carbon steels; (3) high-carbon aluminium steels; (4) pure alloy *PA*

Table VI

NUCLEATION AND GROWTH DATA FROM COMPLETELY GRAPHITIZED SPECIMENS

Steel	Pretreatment	Growth Constant × 10^5, cm./sec.$^{\frac{1}{2}}$
3	W.Q.	1·8
4	W.Q.	1·2
5	W.Q.	1·8
5	C.W.	5·7
6	W.Q.	2·0
PA	W.Q.	1·9
A1	W.Q.	2·2
A2	W.Q.	2·6
A3	W.Q.	3·0
A4	W.Q.	3·1
A4	C.W.	3·0
A4	Ann.	11·1
S1	W.Q.	3·0
S2	W.Q.	4·0
S3	W.Q.	3·0
S3	C.W.	8·1
S3	Ann.	5·4

impurity elements. Such elements might have a further effect upon graphitization by influencing the stability of the carbide.

Effect of Aluminium on Graphite Nucleation

The results show that, for the aluminium steels treated in the presence of oxygen, increased content of metallic aluminium was accompanied by an increased rate of graphitization and more nuclei. There is, however, no correlation between either of these factors and the alumina contents of the steels before treatment. On the oxidation of metallic aluminium in air at 660°C. γ-alumina is formed, but it is not known which oxide is produced on the internal oxidation of steel at this temperature. A foreign particle may promote nucleation if one of its faces is structurally similar to a growing plane of the new phase and γ-alumina shows a structural similarity with graphite on probable growing planes, whereas α-alumina does not. The fit is between the oxygen atoms in the (110) planes of γ-alumina and the atoms in the ($1\bar{1}00$) planes of graphite. The discrepancy in fit is 13% in the a_0 direction of the graphite unit cell and 18% in the c_0 direction. The misfit in the c_0 direction is rather large[16] but the interatomic forces in the graphite in this direction are small and the graphite lattice may be able to adapt itself to the γ-alumina lattice. Furthermore, carbon and oxygen have a high chemical affinity for each other which greatly increases the probability of γ-alumina acting as a foreign nucleus for graphite. Accordingly, it is suggested that γ-alumina is formed on the internal oxidation of steel at 660°C. and that this oxide promotes graphite nucleation. Any effect of α-alumina is thought to be small in comparison with that of γ-alumina.

The results show that 0·07% of aluminium is sufficient to yield a very large number of graphite nuclei; increasing the amount of aluminium beyond this gives increased rates of graphitization and more nuclei.

Effect of Silicon on Graphic Nucleation

Silicon has been shown to accelerate graphitization in a similar manner to aluminium but to a lesser extent. It is suggested that cristobalite is a foreign nucleus for graphite and is formed on the internal oxidation of steel at 660°C. Thus, it can be shown that the (110) planes of cristobalite are similarly arranged to those of γ-alumina and so may nucleate graphite. The misfit is 3% in the a_0 direction and 8% in the c_0 direction, but the layers of oxygen atoms in cristobalite are twice as far apart as in γ-alumina and so it is not so potent a foreign nucleus for graphite.

Effect of Aluminium and of Silicon on Stability of Carbide in Steel

The rate of graphitization corresponding to a given final number of nuclei and the rate of growth of graphite particles were greater for the silicon steels than for the aluminium steels and the iron–carbon alloy, which were materially the same. This observation can be explained if the carbide in silicon steels is less stable than normal iron carbide, as suggested by Harry,[17] and if aluminium does not affect the stability of iron carbide, as suggested by Hall and Fletcher.[18]

The silicon steels did not graphitize readily *in vacuo* and so the effect of silicon on the stability of the carbide is of minor importance compared with its effect on graphite nucleation when the steel is treated in the presence of oxygen.

Graphitization of Plain Carbon Steels

It is difficult to see any correlation between the analyses of the plain carbon steels and the corresponding susceptibilities to graphitization. Carbon content does not appear to be of major importance in the range studied. Also, the chemical method for the determination of metallic aluminium in steel may not be accurate enough to distinguish between the small differences in aluminium content producing large differences in rates of graphitization.

The plain carbon steels had higher contents of carbide stabilizers than the other steels examined and so, as would be expected, the rates of graphitization for a given number of nuclei were lower. The anomalous behaviour of steel 1 may be due to its containing small amounts of the strong carbide stabilizers molybdenum, tungsten, and vanadium.

Effect of Prior Treatment on Subcritical Graphitization

A steel quenched to martensite prior to treatment at 660°C. graphitized more readily than if previously fully annealed; cold-working gave an intermediate effect. This behaviour is difficult to understand, but a possible explanation is as follows.

Specimens quenched or cold-worked before treatment at 660°C. had a fine ferrite grain size before complete graphitization. In the latter case the grains were not elongated in the direction of drawing so that recrystallization must have occurred. The temperature of formation of the ferrite grains would be lowest in the specimens previously quenched, highest in those previously annealed, and intermediate in those previously cold-worked. The coefficient of thermal expansion of ferrite exceeds that of cementite, and so the lower the temperature of ferrite formation the greater will be the stress in

the cementite and the greater its free energy on reaching 660°C. The higher free energy of cementite makes it less stable with respect to graphite and so promotes graphitization.

SUMMARY AND CONCLUSIONS

Graphitization at 660°C. has been studied in 15 plain carbon steels, four high-carbon aluminium steels, three high-carbon silicon steels, and a pure iron-carbon alloy. The results show that :

(i) Graphitization is much slower when the treatment is given *in vacuo* than if oxygen is present
(ii) The more stable steels are sensitive to the partial pressure of oxygen in the atmosphere prevailing during subcritical treatment. The effect of variation in this pressure, in the range 0·2–75 cm., is less with increased instability of the steel, and is negligible for the most unstable steels studied
(iii) If a steel is quenched to martensite before treatment at 660°C. it graphitizes much more readily than if previously annealed; cold-working as a pretreatment produces an intermediate effect
(iv) The presence of metallic aluminium in steels in small quantities, or of silicon in larger quantities, promotes graphitization
(v) The rate of growth of graphite is smaller in aluminium steels than in silicon steels, and still less in plain carbon steels.

A hypothesis has been advanced to account for the effect of aluminium and silicon in promoting graphite nucleation in the presence of oxygen. This suggests that many particles of γ-alumina or of cristobalite are produced when steels containing aluminium or silicon are treated at 660°C. in the presence of oxygen, these oxides acting as foreign nuclei for graphite.

Acknowledgments

Grateful thanks are due to B.I.S.R.A. for a bursary which enabled one of us (R.H.H.) to devote his whole time to this research. Thanks are also due to Mr. W. E. Bardgett of The United Steel Companies Ltd., for providing the steels used in the early stages of this work, to the Superintendent of the Bragg Laboratory for the spectrographic analyses in Table I, to Mr. C. Wollerton for the remaining analyses therein, and to the authors' colleagues for many helpful discussions.

APPENDIX

Approximate Determination of the Growth Rate of Graphite Particles

It has been shown that the growth of a graphite particle follows the theoretical equation due to Zener :

$$r = at^{\frac{1}{2}}$$

where r = Particle radius
t = Time
a = Rate-of-growth constant, a constant for any particular case.

All the graphite particles will grow in accordance with Zener's equation until the areas denuded of cementite around the graphite particles impinge. Further nucleation will continue in the areas between the spheres of influence. The result is that the rate of growth of the first-formed graphite particles decreases rapidly to zero after this impingement occurs.

For the one case in which the rate of nucleation could be determined with reasonable accuracy over a wide range of percentage graphitization it has been shown that the rate of nucleation is constant to about 70% graphitization. If it is assumed that nucleation is random and occurs at a constant rate up to 50% graphitization it can be shown that impingement between the ' spheres of influence ' around the graphite particles occurs at about 50% graphitization.

Mathematical Derivation

Consider a graphite particle formed at time T; from Zener's equation its radius r at time t is given by :

$$r = a(t - T)^{\frac{1}{2}}$$

and therefore its volume v becomes

$$\tfrac{4}{3}\pi a^3(t - T)^{\frac{3}{2}}$$

The assumption is now made that the cementite spheroids are uniformly distributed throughout the steel and that the solubility of carbon in ferrite at 660°C. is negligible compared with the total carbon content of the steel.

Then, the volume of matrix denuded of carbon to form the above particle is

$$V = \tfrac{4}{3}\pi a^3(t - T)^{\frac{3}{2}} \cdot \frac{100 \times 2{\cdot}3}{7{\cdot}85 \times c}$$

where 2·3 = Density of graphite
7·85 = Density of eutectoid steel
c = Carbon content of the steel under consideration, wt.-%.

Therefore the diameter of the denuded matrix (' sphere of influence ') is

$$2aB^{\frac{1}{2}}(t - T)^{\frac{1}{2}}$$

where $B = \dfrac{100 \times 2{\cdot}3}{7{\cdot}85 \times c}$

Considering a cube of side equal to the diameter of the ' sphere of influence ' with the graphite particle at its centre, its side is

$$2aB^{\frac{1}{2}}(t - T)^{\frac{1}{2}}$$

and its volume is

$$v' = 8a^3B\,(t - T)^{\frac{3}{2}}$$

When impingement occurs the volumes of all such cubes surrounding nuclei will occupy the whole specimen, that is,

$$V' = 1 = \int_{T=0}^{T=t} 8a^3B(t - T)^{\frac{3}{2}}\,N\,dT$$

where N = rate of nucleation per c.c.

$$\therefore\ V' = \tfrac{16}{5}\,a^3BNt^{\frac{5}{2}} = 1$$

At impingement

$$t_i = \left(\frac{5}{16a^3BN}\right)^{\frac{2}{5}}$$

However, at time t_i the fraction graphitized $f(g)$ is given by

$$f(g) = \tfrac{4}{3}\pi \int_{T=0}^{T=t_i} a^3B(t - T)^{\frac{3}{2}}\,N\,dT$$

$$= \tfrac{8}{15}\pi\,a^3BNt_i^{\frac{5}{2}}$$

Therefore at time t_i

$$f(g) = \frac{\pi}{6} = 52\%$$

Thus impingement between regions denuded of cementite due to the growth of graphite particles occurs at 52% graphitization.

References

1. G. V. SMITH: *Welding J.*, 1948, vol. 27, pp. 277s–284s.
2. C. R. AUSTIN and M. C. FETZER: *Trans. Amer. Soc. Metals*, 1939, vol. 27, pp. 18–39.
3. C. R. AUSTIN and B. S. NORRIS: *Trans. Amer. Inst. Min. Met. Eng.*, 1938, vol. 131, pp. 349–371; *Metals Technology*, 1938, vol. 5, Tech. Publ. No. 923.
4. C. R. AUSTIN and B. S. NORRIS: *Trans. Amer. Soc. Metals*. 1938, vol. 26, pp. 788–846.
5. C. R. AUSTIN and M. C. FETZER: *Metals Technology*, 1940, vol. 7, Sept., Tech. Publ. No. 1228.
6. C. R. AUSTIN and M. C. FETZER: *Trans. Amer. Soc. Metals*, 1941, vol. 29, pp. 339–351; 1945, vol. 35, pp. 485–529.
7. C. R. AUSTIN and B. S. NORRIS: *Ibid.*, 1942, vol. 30, pp. 425–454.
8. G. V. SMITH, J. A. MACMILLAN, and E. J. DULIS: *Ibid.*, 1951, vol. 43, pp. 692–711.
9. E. J. DULIS and G. V. SMITH: *Ibid.*, 1954, vol. 46, pp. 1318–1329.
10. W. E. DENNIS: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 59–63.
11. W. A. JOHNSON and R. F. MEHL: *Trans. Amer. Inst. Min. Met. Eng.*, 1939, vol. 135, pp. 416–442 ; *Metals Technology*, 1939, vol. 6, Tech. Publ. No. 1089.
12. C. A. WERT: *J. Appl. Phys.*, 1949, vol. 20, pp. 943–949.
13. R. F. MEHL and C. WELLS: *Trans. Amer. Inst. Min. Met. Eng.*, 1937, vol. 125, pp. 429–469; *Metals Technology*, 1937, vol. 4, Tech. Publ. No. 798.
14. E. SCHEIL: *Z. Metallkunde*, 1935, vol. 27, pp. 199–209.
15. C. ZENER: *J. Appl. Phys.*, 1949, vol. 20, pp. 950–953.
16. J. H. VAN DER MERWE: *Disc. Faraday Soc.*, 1949, No. 5, pp. 201–214.
17. E. D. HARRY: *J. Iron Steel Inst.*, 1951, vol. 167, pp. 241–246.
18. A. M. HALL and E. E. FLETCHER: *Trans. Amer. Soc. Mech. Eng.*, 1951, vol. 73, pp. 743–749.

Some Aspects of the $\alpha \rightarrow \gamma$ Transformation of High-Purity Iron

By P. R. Pallister, Ph.D.

SYNOPSIS

Measurements of specific heat, thermal analysis, and measurements of thermal electromotive force have been made on samples of N.P.L. iron. The minimum temperature for the $\alpha \rightarrow \gamma$ transformation and the maximum temperature for the $\gamma \rightarrow \alpha$ transformation are both close to 908·5°C. The transition in either direction may cover a range of temperature, although some degree of progress in the transformation may take place isothermally. 993

IRON containing appreciable impurities exhibits thermal hysteresis in the neighbourhood of the A_3 point. Even for high-purity iron, this phenomenon persists, but the voluminous literature dealing with it is unco-ordinated owing to deficiency in the statements of experimental conditions. The trend of measurements, depending upon the observation of discontinuities in various temperature-sensitive properties of the materials, indicates convergence of the Ac_3 and Ar_3 points as the rate of temperature change approaches zero. Some investigators conclude that the two points coincide at infinitely slow changes of temperature, whilst others incline to the view that a definite gap persists. Experimental evidence[1,2] has also been advanced to show that the two phases, α and γ, exist simultaneously over a range of temperature in varying proportion, with some indefinite equilibrium between them. On the other hand, the transformation has been stated[3,4] to go to completion isothermally at certain given temperatures. X-ray diffraction might be expected to provide a direct solution of this problem, and in fact excellent contributory research in this field has been carried out, but there is disagreement[2,5] about the reversibility of the transformation.

Following an investigation of the specific heat of 99·99% pure iron up to 1250° C.,[6] a detailed survey has now been made in the A_3 region of temperature, yielding information about the progress of the transition between α and γ iron. Further evidence from thermal curves and thermo-electric measurements is adduced to strengthen the interpretation of the results.

Manuscript received 12th May, 1954.

Dr. Pallister, formerly with the Physics Division of the National Physical Laboratory, is now Senior Lecturer at the College of Engineering and Science, Woolwich.

SPECIFIC HEAT

Proceeding as for the earlier specific-heat measurements[6] and using the same annealed sample of iron, attention was concentrated upon the interesting range of temperatures between 900° and 925° C. The specimen was alternately maintained at a steady temperature by control of the vacuum furnace and

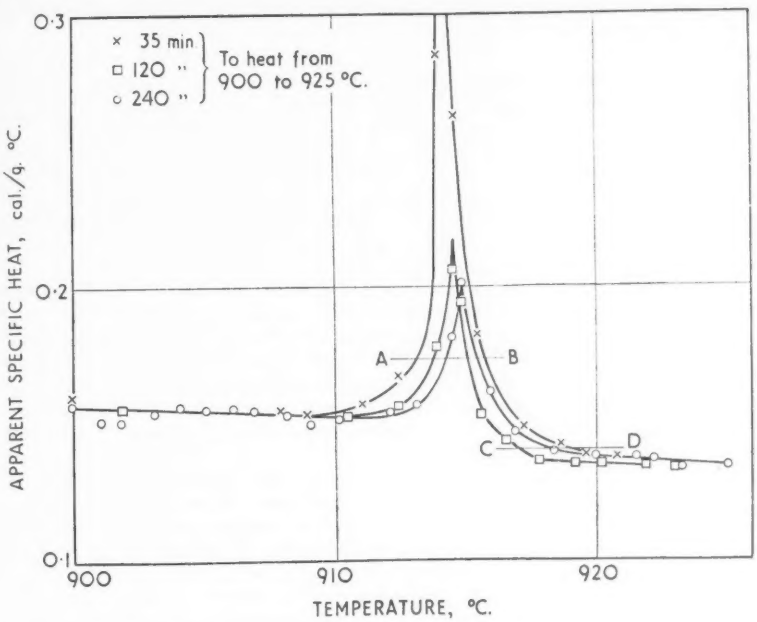


Fig. 1—Dependence of apparent specific heat on duration of isothermal intervals (99·99% iron)

then heated directly through about 1° C. by an electric current. Synchronous heating of a radiation shield very effectually reduced heat losses from the specimen. Each successive temperature increment occupied only about 2 sec. and afforded a value of apparent specific heat, comprising true specific heat and the heat associated with the degree of transformation that took place in that period. The intervals at constant temperature between the measurements varied from one series to another, with the results shown in Fig. 1. Measurements were also made after prolonged soaking at one temperature. All these measurements are certainly accurate to 2%.

THERMAL CURVES

Heating and cooling curves at various rates over the A_3 range were obtained on the same iron specimen *in vacuo*.

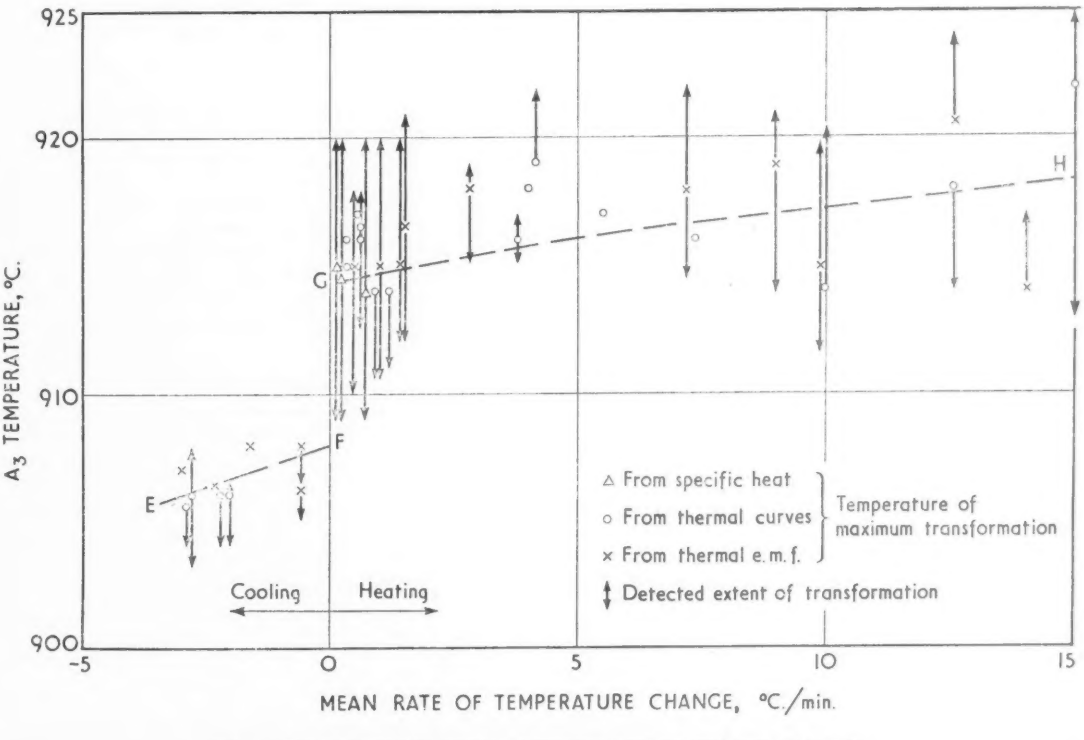


Fig. 2—Transformation range at various heating and cooling rates

For this purpose, the e.m.f. developed in the indicating thermocouple was balanced out by potentiometer at an initial temperature, and the subsequent variation of e.m.f. with time was amplified and recorded photographically. Calibration could be effected by momentarily balancing the e.m.f. at intervals. Many measurements were also made on a small disc of iron, which was cut from the original rod and placed at the most uniformly heated part of the furnace. The condensed results are given in Fig. 2. An arrest is plotted as a distinct point with extensions along the ordinate to indicate the temperatures over which the transition was detected. Two arrests were occasionally noted on a single run.

THERMO-ELECTRIC MEASUREMENTS

For these measurements a length of $\frac{1}{4}$-in. strip of 99·96% iron[7] was used. One end was pared down to wire and welded with platinum and rhodium–platinum wires to form a triple junction. The junction was placed at the most uniformly heated part of the vacuum furnace. Using two vernier potentiometers, several series of simultaneous observations were made on the thermal e.m.f. of iron/platinum and rhodium–platinum/platinum, the latter system having been calibrated for temperature. The thermo-electric power for iron/platinum was then derived and plotted against temperature in a series of curves for certain rates of heating and cooling. The temperatures at which the slopes were greatest are given in Fig. 2, and the extensions along the ordinates again indicate the limits of detection of the transition. Many irregular jumps in the iron/platinum e.m.f. were observed, particularly with falling temperature.

DISCUSSION OF RESULTS

An obvious feature of Fig. 1 is the peak exhibited by each curve, attributable to heat absorbed in the transformation of α iron to γ. The transformation appears at these low mean rates of heating to begin at 909° C., reach a maximum at 915° C., and finish at about 920° C. The explanation for the varying size of the peak must be that, by prolonging the intervals at constant temperature between the specific-heat measurements, more of the transformation is allowed to proceed isothermally and less to contribute to the apparent specific heat. Whether the transformation could proceed to completion isothermally at as low a temperature as 909° C. is not determined, but the evidence points to at least partial conversion of α iron over a range of temperature.

To check the situation at a selected temperature, the iron specimen was soaked for 2 hr. at about 911° C. and then immediately heated to 916·5° C. by a measured amount of energy. The mean apparent specific heat thus determined for a wide span of temperature is shown as AB in Fig. 1; CD is the value determined just after AB and clearly points to a completed transformation. Hence, the transformation must have progressed during both the soaking at 911° C. and the subsequent rise to 916·5° C. The measurement AB is low compared with the large peak in Fig. 1, and so the major part of the transformation had occurred at the temperature of soaking.

In Fig. 2 the transition range of temperature, found by the three methods of observation, is plotted against the mean rate of temperature change. Although some of the curves are not smooth, the large number of results enables general conclusions to be drawn. The temperature of most rapid transformation is seen to rise with rate of heating (GH), and fall with rate of cooling (FE) and it is noticeable that the Ar_3 points in general indicate more abrupt changes than the Ac_3 points. Line EF cuts the temperature axis at 908° C., only 1° C. from the observed onset of Ac_3 at low rates of heating. It is reasonable to conclude that the equilibrium temperature for this allotropic transformation in high-purity iron is $908{\cdot}5 \pm 1°$ C. Close agreement is shown by certain dilatometric investigations,[8] in which, however, the familiar hysteresis phenomenon was not detected.

It is not difficult, in the light of the information given in Fig. 2, to account for many of the apparently conflicting results hitherto obtained concerning the temperature of the 'A_3 point.' It is evident that a sample of iron of well-accredited purity may not make perfectly reproducible progress in either direction of the transformation. During reorientation of the crystals, strains may be set up in the material, both in the lattice and especially at crystal boundaries, and these strains may be relieved irregularly as dislocations are healed. It would be interesting and enlightening to observe whether similar phenomena were manifested in a single crystal.

Acknowledgments

This work was carried out as part of the research programme of the National Physical Laboratory, and the paper is published by permission of the Director of the Laboratory. The iron used, whose production and analysis are recorded elsewhere,[7,9] was produced and supplied by the Laboratory's Metallurgy Division. Temperatures were measured with N.P.L. calibrated thermocouples, considered to be correct to $\pm 1°$ C. The furnace arrangements have already been described.[6] A discussion of the results of this investigation with Dr. Ezer Griffiths and Dr. C. H. M. Jenkins has been greatly appreciated by the author.

References

1. F. M. JAEGER, E. ROSENBOHM, and A. J. ZUITHOFF: *Rec. Trav. Chim. Pays-Bas*, 1938, vol. 57, pp. 1313–1340.
2. A. P. WANGSGARD: *Trans. Amer. Soc. Metals*, 1942, vol. 30, pp. 1303–1322.
3. S. UMINO: *Sci. Rep. Res. Inst. Tôhoku Univ.*, 1927, vol. 16, pp. 1009–1030.
4. B. A. ROGERS and K. O. STAMM: *Metals Technology*, 1941, vol. 8, Tech. Publ. No. 1388.
5. S. D. SMITH: *Trans. Amer. Soc. Metals*, 1938, vol. 26, pp. 255–262.
6. P. R. PALLISTER: *J. Iron Steel Inst.*, 1949, vol. 161, pp. 87–90.
7. F. ADCOCK and C. A. BRISTOW: *Proc. Roy. Soc.*, 1936, vol. 153, ser. A, pp. 172–200.
8. C. WELLS, R. A. ACKLEY, and R. F. MEHL: *Trans. Amer. Soc. Metals*, 1936, vol. 24, pp. 46–66.
9. F. ADCOCK: *Journal of the Society for Chemical Industry*, 1940, vol. 59, pp. 28–31.

Convection and the Heating of Scrap

A THEORETICAL DISCUSSION

By L. F. Daws, M.Sc., and R. D. Collins

SYNOPSIS

An attempt is made to estimate theoretically the decrease in the melting time of the charge in an O.H. furnace which can be caused by convective heat transfer from the flame gases that penetrate to parts of the charge which are not heated directly by radiation from the flame, roof, walls, etc.

It is shown that in practice the thermal conductivity per unit thickness of the body of the charge is as great as that of the heat-transfer convection coefficient from the gases to the body (*i.e.*, the Nusselt number is about unity) and that, as a consequence, the time required to heat the charge is reduced by at least 25% for complete penetration. It is shown also that if the temperature of the penetrating gases is 10% greater than that of the radiant source, complete penetration gives a 10% reduction in the heating time.

990

THE problem of how to decrease the time required to melt scrap in the O.H. furnace has long been one of concern to the industry.

In the process of heating, the top layers of scrap receive heat principally by radiation from the flame, the furnace roof, and walls, and therefore the rate of heating of these layers is rapid, but the rate of heating of the lower layers is necessarily much less, owing to the nature of the heat transfer to them. This is a very complex process in which both radiation and conduction play their part, but the effective conductivity of the piled scrap, if it can be said to have such a property, is much smaller than that of the scrap metal itself.

It has been suggested that this obstruction to heat transfer might be overcome if the hot flame gases penetrated to the lower layers of scrap. These layers would then receive heat by convection and the whole process of melting would be speeded up.

In this paper the problem is considered theoretically with a view to determining the merit of increasing the rate of heating in this way. To do this it is necessary to idealize the process, but it is suggested that the simplifying assumptions will not invalidate the conclusions.

IDEALIZED PROBLEM

To make the theoretical examination as simple as possible a pile of scrap will be treated as though it were a homogeneous porous body of material possessing an effective thermal conductivity k, a density ρ, and a specific heat c. These properties and particularly the conductivity will vary with the fractional voidage of the body and with temperature. This temperature variation will, however, be neglected.

For simplicity the porous body will be treated as an infinite slab, *i.e.*, in the Cartesian co-ordinate notation of Fig. 1, the porous body will be treated in the form of a slab of uniform depth L in the x direction, but will be supposed to extend indefinitely in the horizontal plane.

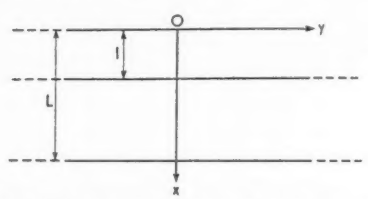


Fig. 1—Idealized infinite slab of scrap

The material of the body initially at a uniform temperature will be supposed to receive heat by two mechanisms operating simultaneously. Firstly, heat will be transferred to the surface $x = 0$ in proportion to the difference in temperature between the surroundings and the surface. Secondly, throughout a finite layer beneath the surface each element of volume will receive a flow of heat from the flame gases proportional to the temperature difference between the gas and the volume element of material. These processes will correspond in idealized form to radiation or convection to the surface (linearized for simplicity) and convection from gases penetrating to a given depth. The base of the porous body will be assumed impervious to heat flow.

In this way it is possible to calculate Q, the quantity of heat per unit area transferred to the material in time t in terms of the following quantities: the thermal conductivity k, density ρ, and specific heat c of the material; the initial temperature difference T_e between the gas and the body; the initial temperature difference T_R between the roof and the body; the depth of material L and of the penetrated layer l; and the constants of proportionality H and h of the two heat-transfer processes. It is mathematically more convenient to consider the quantities:

$Q/\rho cLT_R$, the proportion of heat, ρcLT_R, transferred per unit area up to a time t

$Nu_0 = HL/k$, a Nusselt number of surface heat transfer

Paper SM/A/135/53 of the Steel Practice Committee of the Steelmaking Division of the British Iron and Steel Research Association, received on 20th January, 1954. The views expressed are the authors', and are not necessarily endorsed by the Committee as a body.

Mr. Daws is in the Physics Department of the D.S.I.R. Building Research Station, Garston, and Mr. Collins is with the U.K. Atomic Energy Authority in Lancashire.

$Nu = hlL/k$, a modified Nusselt number of volume heat transfer
$\tau = kt/\rho cL^2$, a dimensionless time
T_c/T_R, the ratio of the temperature of the gas to that of the roof
$\Omega = l/L$, the ratio of the depth of penetration to depth of material.

Although an exact solution has been found for the general case, so that with some labour any given case can be computed, it is instructive as well as being simpler to study the extreme conditions under which the solution holds.

The case of $Nu_0 = 0$ corresponds to no surface heat transfer as would apply if the heat transfer were wholly by convection from gases freely penetrating the charge, the radiation to the surface being negligible.[1] On the other hand $Nu_0 = \infty$ is an approximation to the conditions where the radiation heat transfer is so large that the principal obstacle to melting is the slow conduction of heat through the scrap. In this case convection without penetration can have no effect for surface heat transfer is already so great that the surface is at the same temperature as the gas, but penetration can produce a considerable effect even with a comparatively low convection heat transfer. The possible range of the effect is shown by a comparison of $\Omega = 0$ and $\Omega = 1$ for various values of Nu.

FORMULATION OF THE IDEALIZED PROBLEM

Suppose that the surface of the porous body at $x = 0$ in Cartesian co-ordinates (Fig. 1) receives heat by radiation and convection at a rate H (cal./sq. cm. sec. ° C.) per unit area per ° C. temperature difference between the surface and its surroundings; suppose also that gas penetrates to a depth l (cm.) into the body in such a manner that an amount of heat h (cal./c.c. sec. ° C.) is transferred by convection to every unit volume of the body ($0 < x < l$) per second per ° C. temperature difference between the gas and the unit volume. Then, if the base of the body at $x = L$ is impervious to heat, and the initial temperature of the body is uniform, the following equations will hold:

$$k\frac{\partial^2\theta_1}{\partial x^2} = \rho c\frac{\partial\theta_1}{\partial t_1} + h(\theta_1 - T_c),\ 0 < x < l \quad \text{.....(1)}$$

$$-k\frac{\partial\theta_1}{\partial x} = H(T_R - \theta_1),\ x = 0 \quad \text{.....(2)}$$

$$\left.\begin{aligned} -k\frac{\partial\theta_1}{\partial x} &= -k\frac{\partial\theta_2}{\partial x} \\ \theta_1 &= \theta_2 \end{aligned}\right\},\ x = l \quad \text{.....(3)}$$

$$k\frac{\partial^2\theta_2}{\partial x^2} = \rho c\frac{\partial\theta_2}{\partial t},\ l < x < L \quad \text{.....(4)}$$

$$\frac{\partial\theta_2}{\partial x} = 0,\ x = L \quad \text{.....(5)}$$

$$\theta_1 = \theta_2 = 0,\ t = 0 \quad \text{.....(6)}$$

where

θ_1 (° C.) is the difference between the temperature of the body at a depth x, $0 < x < l$, at a time t and its initial temperature
θ_2 (° C.) is the difference between the temperature of the body at a depth x, $l < x < L$, at a time t and its initial temperature
T_R (° C.) is the difference between the temperature of the surroundings of the surface $x = 0$ and the body's initial temperature
T_c (° C.) is the difference between the temperature of the penetrating gases and the initial temperature of the body.

Making the normalizing substitutions

$$\left.\begin{aligned} x = L\xi,\ l = L\Omega,\ kt/\rho cL^2 &= \tau \\ hL^2/k = N,\ N\Omega = Nu,\ HL/k &= Nu_0 \end{aligned}\right\} \quad \text{.....(7)}$$

the above equations become:

$$\frac{\partial^2\theta_1}{\partial\xi^2} = \frac{\partial\theta_1}{\partial\tau} + N(\theta_1 - T_c),\ 0 < \xi < \Omega \quad \text{.....(8)}$$

$$\frac{\partial\theta_1}{\partial\xi} = Nu_0(\theta_1 - T_R),\ \xi = 0 \quad \text{.....(9)}$$

$$\left.\begin{aligned} \frac{\partial\theta_1}{\partial\xi} &= \frac{\partial\theta_2}{\partial\xi} \\ \theta_1 &= \theta_2 \end{aligned}\right\},\ \xi = \Omega \quad \text{.....(10)}$$

$$\frac{\partial^2\theta_2}{\partial\xi^2} = \frac{\partial\theta_2}{\partial\tau},\ \Omega < \xi < 1 \quad \text{.....(11)}$$

$$\frac{\partial\theta_2}{\partial\xi} = 0,\ \xi = 1 \quad \text{.....(12)}$$

$$\theta_1 = \theta_2 = 0,\ \tau = 0 \quad \text{.....(13)}$$

Using the well-known Laplace transformation

$$L\{f(\tau)\} = \int_0^\infty e^{-p\tau} f(\tau)d\tau = \bar{f}(p) \quad \text{.....(14)}$$

these become:

$$\frac{d^2\bar{\theta}_1}{d\xi^2} - (p + N)\bar{\theta}_1 = -\frac{NT_c}{p},\ 0 < \xi < \Omega \quad \text{.....(15)}$$

$$\frac{d\bar{\theta}_1}{d\xi} = Nu_0\left(\bar{\theta}_1 - \frac{T_R}{p}\right),\ \xi = 0 \quad \text{.....(16)}$$

$$\left.\begin{aligned} \frac{d\bar{\theta}_1}{d\xi} &= \frac{d\bar{\theta}_2}{d\xi} \\ \bar{\theta}_1 &= \bar{\theta}_2 \end{aligned}\right\},\ \xi = \Omega \quad \text{.....(17)}$$

$$\frac{d^2\bar{\theta}_2}{d\xi^2} - p\bar{\theta}_2 = 0,\ \Omega < \xi < 1 \quad \text{.....(18)}$$

$$\frac{d\bar{\theta}_2}{d\xi} = 0,\ \xi = 1 \quad \text{.....(19)}$$

Now a solution satisfying equations (15) and (16) is of the form

$$\bar{\theta}_1 = \frac{NT_c}{p(p + N)} + \left\{A(p) - \frac{Nu_0[(T_c - T_R)N - T_Rp]}{p(p + N)}\right\} e^{\sqrt{(p + N)}.\xi}/2[Nu_0 - (p + N)^{\frac{1}{2}}] - \left\{A(p) + \frac{Nu_0[(T_c - T_R)N - T_Rp]}{p(p + N)}\right\} e^{-\sqrt{(p + N)}.\xi}/2[Nu_0 + (p + N)^{\frac{1}{2}}] \quad \text{.....(20)}$$

and similarly a solution satisfying equations (18) and (19) is

$$\bar{\theta}_2 = a(p)\ \mathrm{ch}\ p^{\frac{1}{2}}(1 - \xi) \quad \text{.....(21)}$$

where $A(p)$ and $a(p)$ are arbitrary functions of p.

It follows that Q, the total heat in the body per unit area of the surface at time τ, is given by

$$\frac{\bar{Q}}{\rho cL} = \int_0^\Omega \bar{\theta}_1 d\xi + \int_\Omega^1 \bar{\theta}_2 d\xi$$

$$= \frac{NT_c\Omega}{p(p + N)} + \left\{A(p) - \frac{Nu_0[(T_c - T_R)N - T_Rp]}{p(p + N)}\right\} [e^{\sqrt{(p + N)}.\Omega} - 1]/2(p + N)^{\frac{1}{2}}[Nu_0 - (p + N)^{\frac{1}{2}}] - \left\{A(p) + \frac{Nu_0[(T_c - T_R)N - T_Rp]}{p(p + N)}\right\} [1 - e^{-\sqrt{(p + N)}.\Omega}]/2(p + N)^{\frac{1}{2}}[Nu_0 + (p + N)^{\frac{1}{2}}] + \frac{a(p)\ \mathrm{sh}\ p^{\frac{1}{2}}(1 - \Omega)}{p^{\frac{1}{2}}} \quad \text{.....(22)}$$

When $A(p)$ and $a(p)$ are chosen to satisfy equations (17) it can be shown that

$$\frac{\bar{Q}}{\rho c \bar{L}} = \frac{N T_c \Omega}{p(p+N)} + \frac{NNu_0[(T_c+T_R)p-(T_c-T_R)N]\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)}{p^{3/2}(p+N)f(p)} + \frac{g(p)}{p^2(p+N)f(p)} \quad \ldots\ldots(23)$$

where

$$f(p) = [Nu_0\,\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega) + p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)](p+N)\,\mathrm{ch}\,(p+N)^{\frac{1}{2}}\Omega + [(p+N)\,\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega) + Nu_0 p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)](p+N)^{\frac{1}{2}}\,\mathrm{sh}\,(p+N)^{\frac{1}{2}}\Omega$$

and

$$g(p) = Nu_0[N^2T_c - p^2T_R - pN(T_c-T_R)]p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{ch}\,(p+N)^{\frac{1}{2}}\Omega + Nu_0[p^2T_R - pN(T_c-T_R)](p+N)^{\frac{1}{2}}\,\mathrm{sh}\,(p+N)^{\frac{1}{2}}\Omega\,\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega) + N^2T_c\,p^{\frac{1}{2}}(p+N)^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{sh}\,(p+N)^{\frac{1}{2}}\Omega$$

Now it is known on a physical basis, and it can be shown mathematically, that $f(p)$ is zero only for real negative values of p. Thus it is possible to invert equation (23) and to obtain Q as a function of τ for all values of the parameters. However, since no experimental evidence exists from which ranges for N, Nu_0, Ω, etc., can be derived, it will be better to concentrate attention on the extreme conditions under which equation (23) is valid. Thus consider first the effect of penetration alone.

EFFECT OF PENETRATION ALONE

Writing $Nu_0 = 0$ and $T_c = T_R = T$ in equation (23) gives

$$\frac{\bar{Q}}{\rho c \bar{L} T} = \frac{N\Omega}{p(p+N)} + \frac{N^2\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{sh}\,(p+N)^{\frac{1}{2}}\Omega}{p^{3/2}(p+N)^{3/2}[p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{ch}\,(p+N)^{\frac{1}{2}} + (p+N)^{\frac{1}{2}}\,\mathrm{sh}\,(p+N)^{\frac{1}{2}}\Omega\,\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega)]} \quad \ldots(24)$$

that is

$$\frac{\bar{Q}}{\rho c \bar{L} T} = \frac{Nu\Omega}{p(\Omega p+Nu)} + \frac{Nu^2}{p^2(\Omega p+Nu)^2[\coth\,(\Omega p+Nu)^{\frac{1}{2}}\Omega^{\frac{1}{2}}]} + \frac{\coth\,p^{\frac{1}{2}}(1-\Omega)}{\left(p+\frac{Nu}{\Omega}\right)^{\frac{1}{2}}p^{\frac{1}{2}}} \quad \ldots\ldots(25)$$

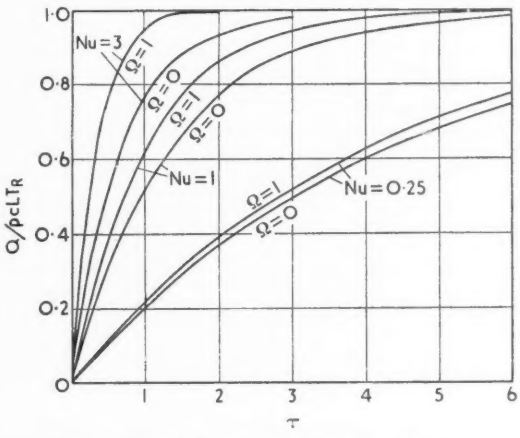


Fig. 2—Effect of penetration alone, $Nu_0 = 0$

where

$$Nu = N\Omega$$

If Nu is kept constant for all Ω, it will be possible to see from (25) the advantage that penetration alone will have. Thus

$$\frac{\bar{Q}}{\rho c \bar{L} T} = \frac{Nu\,\mathrm{sh}\,p^{\frac{1}{2}}}{p^{3/2}[p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}} + Nu\,\mathrm{ch}\,p^{\frac{1}{2}}]},\ \Omega = 0 \quad \ldots\ldots(26)$$

$$= \frac{Nu}{p(p+Nu)},\ \Omega = 1 \quad \ldots\ldots(27)$$

Inverting these:

$$\frac{Q}{\rho c \bar{L} T} = 1 - \sum_{n=1}^{\infty} \frac{2Nu^2\exp(-\alpha_n^2\tau)}{\alpha_n^2[Nu^2+Nu+\alpha_n^2]},\ \Omega = 0 \quad \ldots(28)$$

where α_n satisfy the equation

$$\alpha\tan\alpha = Nu$$

and

$$\frac{Q}{\rho c \bar{L} T} = 1 - e^{-Nu\tau},\ \Omega = 1 \quad \ldots\ldots(29)$$

In Fig. 2 these solutions have been plotted for several values of Nu.

EFFECT OF PENETRATION WITH A QUENCH AT THE SURFACE

In practice it is likely that the temperature of the outer layer of scrap will rise rapidly and this would correspond to something approaching a quench condition at the surface of the porous body.

Therefore making Nu_0 tend to infinity and $T_R = T_c$ in equation (23):

$$\frac{\bar{Q}}{\rho c \bar{L} T} = \frac{Nu\Omega}{p(\Omega p+Nu)} + \frac{2Nu\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)}{p^{\frac{1}{2}}(\Omega p+Nu)F(p)} + \frac{G(p)}{\Omega p^2(\Omega p+Nu)F(p)} \quad \ldots\ldots(30)$$

where

$$F(p) = p^{\frac{1}{2}}\left(p+\frac{Nu}{\Omega}\right)^{\frac{1}{2}}\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{sh}\,(\Omega p+Nu)^{\frac{1}{2}}\Omega^{\frac{1}{2}} + \left(p+\frac{Nu}{\Omega}\right)\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{ch}\,(\Omega p+Nu)^{\frac{1}{2}}\Omega^{\frac{1}{2}}$$

and

$$G(p) = (Nu^2+\Omega^2p^2)p^{\frac{1}{2}}\,\mathrm{sh}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{ch}\,(\Omega p+Nu)^{\frac{1}{2}}\Omega^{\frac{1}{2}} + p^2\left(p+\frac{Nu}{\Omega}\right)^{\frac{1}{2}}\Omega^2\,\mathrm{ch}\,p^{\frac{1}{2}}(1-\Omega)\,\mathrm{sh}\,(\Omega p+Nu)^{\frac{1}{2}}\Omega^{\frac{1}{2}}$$

so that

$$\frac{\bar{Q}}{\rho c \bar{L} T} = \frac{\tanh p^{\frac{1}{2}}}{p^{3/2}},\ \Omega = 0 \quad \ldots\ldots(31)$$

$$= \frac{Nu}{p(p+Nu)} + \frac{\tanh\,(p+Nu)^{\frac{1}{2}}}{(p+Nu)^{3/2}},\ \Omega = 1 \quad \ldots\ldots(32)$$

Inverting these it is found that

$$\frac{Q}{\rho c \bar{L} T} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2}\exp\left[\frac{-(2n+1)^2\pi^2\tau}{4}\right],\ \Omega = 0,\ Nu_0 = \infty,\ T_c = T_R = T \quad \ldots\ldots(33)$$

$$= 1 - e^{-Nu\tau}\sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2}\exp\left[\frac{-(2n+1)^2\pi^2\tau}{4}\right],\ \Omega = 1,\ Nu_0 = \infty,\ T_c = T_R = T \quad \ldots\ldots(34)$$

Similarly, when $T_c \neq T_R$:

$$\frac{\bar{Q}}{\rho c \bar{L} T_R} = \frac{\tanh p^{\frac{1}{2}}}{p^{3/2}},\ \Omega = 0,\ Nu_0 = \infty \quad \ldots\ldots(35)$$

$$= \frac{NuT_c/T_R}{p(p+Nu)} + \frac{\tanh\,(p+Nu)^{\frac{1}{2}}}{p(p+Nu)^{\frac{1}{2}}} - \frac{NuT_c\tanh\,(p+Nu)^{\frac{1}{2}}}{T_R p(p+Nu)^{3/2}},\ \Omega = 1,\ Nu_0 = \infty \quad (36)$$

so that

$$\frac{Q}{\rho c L T_R} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2} \exp\left[\frac{-(2n+1)^2\pi^2\tau}{4}\right], \quad \Omega = 0 \quad \ldots\ldots\ldots(37)$$

$$= \frac{T_c}{T_R} - \left(\frac{T_c}{T_R} - 1\right)\frac{\tanh (Nu)^{\frac{1}{2}}}{(Nu)^{\frac{1}{2}}} - e^{-Nu\tau} \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2}\left\{\frac{(2n+1)^2\pi^2 + 4NuT_c/T_R}{(2n+1)^2\pi^2 + 4Nu}\right\} \exp\left[\frac{-(2n+1)^2\pi^2\tau}{4}\right] \quad \ldots\ldots\ldots\ldots(38)$$

Solutions (33) and (34) have been plotted in Fig. 3*a* for $\Omega = 0$, which corresponds to no penetration, and $Nu = 0{\cdot}25$, 1, and 3 with $\Omega = 1$. Solutions (37) and (38) are plotted in Fig. 3*b* for the same values of Nu and for $T_c/T_R = 1$ and $1{\cdot}1$.

DISCUSSION OF RESULTS

The idealized problem of heating and melting scrap has been described and in the three preceding sections this idealized problem has been solved. For convenience the solutions are represented in terms of the dimensionless quantities $Q/\rho c L T_R$, Nu_0, Nu, τ, and T_c/T_R. For the reasons given, only the extreme conditions under which the general solution is valid have been considered.

Figure 2 gives the solution when $Nu_0 = 0$. This corresponds to no surface heat transfer, which would apply if the heat transfer were wholly by convection from gases freely penetrating the charge, radiation to the surface being negligible. It is apparent that the effect of penetration in reducing the heating time becomes of importance for $Nu > 1$. For $Nu = 1$ the time for Q to reach $0{\cdot}9\rho c L T$ is reduced by 25% owing to complete penetration and this saving increases with Nu.

In Fig. 3*a* the solution when $Nu_0 = \infty$ is represented. This is an approximation to the condition in an O.H. furnace when the radiation heat transfer is so large that the principal obstacle to heat flow is the slow conduction of heat through the scrap. In this case convection with no penetration can have no effect, as the surface heat transfer is already too large for any extra convection transfer to have effect. Once again it is apparent that penetration has an important effect for $Nu > 1$. In fact the reduction in the heating time for Q to reach $0{\cdot}9\ \rho c L T$ is greater in this case than with no radiation at the surface. It is 30% for $Nu = 1$.

It would therefore be correct to deduce that for a given Nu_0 at the surface the time for Q to reach $0{\cdot}9\rho c L T$ would be reduced by at least 25% owing to complete penetration for $Nu > 1$.

A further condition which can be studied is that of having a gas temperature T_c greater than that of the radiant source. The effect of this is shown in Fig. 3*b* for $Nu_0 = \infty$, where $Q/\rho c L T_R$ is plotted against τ for the same values of Nu and Ω as in Figs. 2 and 3*a*, but for $T_c/T_R = 1{\cdot}1$ and 1. Once again a worthwhile reduction in heating time becomes apparent for $Nu > 1$. The reduction is about 10% for $Nu = 1$.

SIZE OF NUSSELT NUMBER IN PRACTICE

It has been shown that a worthwhile advantage is to be gained by heating the scrap by convection from penetrating gases, in addition to radiation heating at the surface, if the modified Nusselt number hlL/k is in practice of the order of 1, or greater. To see whether this is so a conventional calculation will be carried out.

Consider[2] an O.H. bath of capacity 80 tons and area 380 sq. ft. and suppose the time required to melt the scrap is 6 hr. Suppose that the radiation heat-transfer coefficient H is 3×10^{-2} cal./cm. ° C. sec., corresponding to radiation from the roof, etc., at 1650° C. to the surface of the scrap at 1400° C., and that the specific heat of the scrap metal is $0{\cdot}16$ cal./g. ° C.

Then the mass of scrap per unit area of bath

$$= L\rho = 80/380 \text{ tons/sq. ft.}$$

$$= \frac{80}{380} \times 2240 \times 0{\cdot}4882 \text{ g./sq. cm.} \quad \ldots\ldots\ldots(39)$$

Then

$$Nu_0\tau = \frac{HL}{k} \cdot \frac{kt}{\rho c L^2} = \frac{Ht}{\rho c L}$$

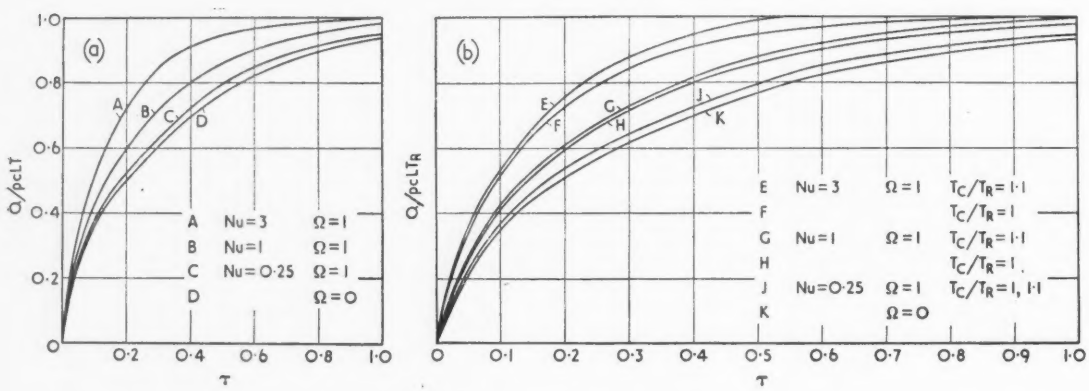


Fig. 3—Solutions given by (*a*) equations (33) and (34), $Nu_0 = \infty$; (*b*) equations (37) and (38), $Nu_0 = \infty$

$$= \frac{0{\cdot}03 \times (6 \times 3600)}{0{\cdot}16\left(\frac{80}{380} \times 2240 \times 0{\cdot}4882\right)}$$

$$\simeq 17{\cdot}6 \quad \ldots\ldots (40)$$

But from equation (28) with radiation at the surface and convection

$$\frac{Q}{\rho c L T_R} = 1 - \sum_{n=0}^{\infty} \frac{2Nu_0^2 \exp(-\alpha_n^2 \tau)}{\alpha_n^2[Nu_0^2 + Nu_0 + \alpha_n^2]} \quad \ldots\ldots (41)$$

where $\alpha \tan \alpha = Nu_0$ $\ldots\ldots (42)$

Thus approximately

$$\left(1 - \frac{Q}{\rho c L T_R}\right)\frac{\alpha_0^2[Nu_0^2 + Nu_0 + \alpha_0^2]}{2Nu_0^2} = \exp(-\alpha_0^2 \tau) \quad (43)$$

If the Q required to melt the scrap is $0{\cdot}9\rho c L T_R$, then using the value from equation (40)

$$\frac{0{\cdot}1\alpha_0^2[Nu_0^2 + Nu_0 + \alpha_0^2]}{2Nu_0^2} = \exp(17{\cdot}6\alpha_0^2/Nu_0) \quad \ldots (44)$$

Solving this equation iteratively by means of (42) gives

$$Nu_0 \simeq 20 \ldots\ldots (45)$$

so that effectively there is a quench at the scrap surface, *i.e.*, the surface temperature is the same as that of the radiant source.

To obtain an estimate of Nu the formula given in "Technical Data on Fuel"[3] for the heat transfer coefficient to banks of tubes will be used. The coefficient thus obtained will correspond to hl in the notation of this paper. Otherwise, in the notation of "Technical Data on Fuel":

$$hl = 0{\cdot}32 \frac{k}{D}\left(\frac{VD}{\nu}\right)0{\cdot}6 \quad \ldots\ldots (46)$$

The formula will give a conservative value for hl since it is defined per unit area of tube surface, whereas hl is defined per unit area of bath. This certainly means that the hl obtained should be multiplied by a factor greater than 1.

The gas properties in (46) should be taken at the film temperature, 1000° C. say. Then using the properties of air, $\gamma = 1{\cdot}76$ c.g.s., $k = 1{\cdot}88 \times 10^{-4}$ cal./cm. ° C. sec., and supposing that the velocity of the gas is 100 ft./sec. and $D = 1$ ft.:

$$hl = 1{\cdot}2 \times 10^{-3} \text{ cal./sq. cm. } ^\circ \text{C.} \quad \ldots\ldots (47)$$

But

$$\frac{Nu}{Nu_0} = \frac{hlL}{K} \Big/ \frac{HL}{K} = \frac{hl}{H} \quad \ldots\ldots (48)$$

Therefore from (46) and remembering that $H = 3 \times 10^{-2}$ cal./sq. cm. sec.

$$Nu = \frac{1{\cdot}2 \times 10^{-3}}{3 \times 10^{-2}} \times 20$$

$$= 0{\cdot}8 \ldots\ldots (49)$$

Since this is if anything a conservative value it has been shown that Nu is at least of the order of 1 and in view of the discussion (p. 352) there is reason to believe that the melting time of scrap can be considerably reduced by convection penetration.

CONCLUSIONS

From a consideration of the time taken to melt a charge in an O.H. furnace for a minimum estimate of the radiation which must fall on its surface, it is shown that the principal obstacle to heat transfer lies within the charge. A considerable reduction in heating time may thus be obtained by transferring heat directly to the interior of the body of the charge. If hot gases penetrate to parts of the charge which are not heated directly by radiation from above the effect of convection may be important even though the heat transfer coefficient of convection under furnace conditions is much smaller than that of radiation. It should not be forgotten that where penetration occurs by the passage of gases between large blocks of charge, radiation from the penetrating gases may be as important as convection.

To estimate the effect of convection a simplified mathematical model has been considered in which the charge, which consists of large masses of material interspersed with numerous channels and passages, is represented as a homogeneous layer through which gas can penetrate. The charge is supposed to be placed cold on an insulating hearth and subsequently heated by the two forms of heat transfer considered. Thus the effect of charging during melting must be regarded as a reduction in the effective depth to which heat has to be conducted.

The effective conductivity of the charge and its effective depth are difficult to estimate, but since it is only the product of these quantities which enters into the dimensionless heat-transfer number, *i.e.*, modified Nusselt number (the parameter necessary for the calculation), neither need be determined separately. An estimation of the product can fortunately be made by assuming no penetration and comparing true melting times with those given by the calculation.

The order of magnitude of acceleration of heating due to penetration has been calculated and it is shown that for a convection Nusselt number of unity, which is a conservative estimate of conditions to be expected in a furnace, complete penetration would reduce the heating time by 30%. As the effect of 50% penetration is considerably more than 50% of the effect of complete penetration, the possibility of penetration producing an appreciable effect appears to be established.

Particularly with flames of low luminosity it is possible for the gas temperature to be considerably higher than that associated with the radiation falling on the charge, so the effect of raising the gas temperature without changing the radiation at the surface has been calculated and a 10% higher temperature is found to reduce the melting time by 10% under the same conditions.

These results suggest that a careful study of the behaviour of the charge when melting and the extent to which gases can penetrate it could lead to important advances in melting practice.

References

1. K. P. Perry: Private communication.
2. J. H. Chesters and M. W. Thring: The Influence of Port Design on Open-Hearth Furnace Flames, Spec. Rep. No. 37: 1946, London, The Iron and Steel Institute.
3. H. M. Spiers (Ed.): "Technical Data on Fuel," p. 241: 1950, London, British National Committee of the World Power Conference.

Thermodynamic Calculation of Slag Equilibria—II

INFLUENCE ON CATION EXCHANGE EQUILIBRIA CAUSED BY CATIONS NOT TAKING PART IN THE EXCHANGE

By K. Grjotheim

SYNOPSIS

The paper (with the cycle) gives the theoretical (thermodynamic) explanation of the experimental fact that ionic equilibria are not greatly influenced by ions of the same sign as those taking part in the equilibria. 982

THE influence of the other cations on a cation exchange equilibrium is usually a second-order effect compared with the influence of the anions present. This may be shown by using a cyclic process analogous to the one used by deriving the equation for the dependence of the cation-exchange equilibrium on the anions.[1]

To demonstrate this, one may consider an equilibrium reaction: *e.g.*, the exchange of manganese and iron between a molten iron phase and a slag that contains n different anions, but only the cations Mn^{2+} and Fe^{2+}:

$$Fe^{2+}(slag) + \underline{Mn} = \underline{Fe} + Mn^{2+}(slag).$$

The dependence of the equilibrium constant on the anions present is then given by the equation:

$$\log K_{mix} = \sum_{i=1}^{n} N'_{anion_i} \log K_i$$
$$= N'_{O^{2-}} \log K_O + N'_{SiO_4^{4-}} \log K_{SiO_4} + \ldots \text{etc.}$$

where K_O is the equilibrium constant in a pure oxide system (containing only the anion O^{2-} and the cations Mn^{2+} and Fe^{2+}), and K_{SiO_4} is the equilibrium constant in a pure orthosilicate system. The N'_{ion} is the electrically equivalent fraction.

If cations other than Mn^{2+} and Fe^{2+} are present in the slag, however, the cyclic process shows that $\log K_O$ must be replaced by $\log K_O^*$ where K_O^* is an equilibrium constant referring to 'mixed standard states.' In such a 'mixed standard state' the concentration of, say, FeO is equal to $x = N_{Fe^{2+}} + N_{Mn^{2+}}$ in a mixture of CaO, MgO, etc., and where the Ca/Mg ratio, etc., is the same as that in the slag. A similar standard state should be used for MnO.

Using the following cyclic process, a thermodynamic correlation may be derived for the equilibrium constant K_O for the 'pure' system and K_O^* for the mixed cations system.

In an analogous way, the relations between the 'mixed' and the 'pure' equilibrium constants in the other anion systems (K_{PO_3}, K_{SiO_4}, etc.) for the iron–manganese equilibrium can also be derived:

$$\begin{array}{ccc} Fe_x(M_{1-x})O + x\,\underline{Mn} & \xrightarrow{(1)} & x\,\underline{Fe} + Mn_x(M_{1-x})O \\ \uparrow (4) & & \downarrow (2) \\ x\,FeO + x\,\underline{Mn} & \xleftarrow{(3)} & x\,\underline{Fe} + x\,MnO \end{array}$$

Reaction (1)—x moles of FeO in a mixture of $(1 - x)$ moles of different metal oxides ($M = Ca^{2+}$, Mg^{2+}, etc.) react reversibly with x moles of Mn to form Fe and MnO in the same mixture:

$$\Delta G_1 = -xR'T \log K^*_O,$$

where $R' = R \ln 10$.

Reaction (2)—x moles of MnO in the cation mixture are separated from the mixture to form pure liquid MnO:

$$\Delta G_2 = -xR'T \log a^*_{MnO},$$

where a^*_{MnO} is the activity of MnO in the oxide mixture referred to pure liquid MnO.

Reaction (3)—x moles of pure liquid MnO react reversibly with x moles of Fe to form Mn and pure liquid FeO:

$$\Delta G_3 = +xR'T \log K_O.$$

Reaction (4)—x moles of pure liquid FeO are dissolved in the oxide mixture of $(1 - x)$ moles of MnO:

$$\Delta G_4 = +xR'T \log a^*_{FeO},$$

where a^*_{FeO} is similar to a^*_{MnO}.

For the total cycle, the changes in ΔG must be zero; hence:

$$\log K_O^* = \log K_O + \log \frac{a^*_{FeO}}{a^*_{MnO}}.$$

Because the concentrations x of FeO and MnO in the two 'mixed standard states' are equal, it follows that:

$$\log K_O^* = K_O + \log \frac{\gamma^*_{FeO}}{\gamma^*_{MnO}}.$$

The quantities γ^*_{FeO} and γ^*_{MnO} are the activity coefficients in the 'mixed standard states' referring to pure liquid FeO and MnO, respectively, at the same temperature as the standard states. The coefficients can be independently determined by experiments.

As only the ratio of the two activity coefficients will affect $\log K_O^*$, it is likely that an extrapolation of $\log K_{mix}^*$ to $N'_{O^{2-}} = 1$, where

$$K' = \frac{(Mn^{2+})\,[Fe]}{(Fe^{2+})\,[Mn]}$$

Manuscript received 14th December, 1953.

Mr. Grjotheim has a Fellowship at the Institute of Silicate Science at the Norwegian Institute of Technology, Trondheim, Norway.

(instead of activities containing the concentration terms ' ionic fractions in the slag phase ' and ' atomic fraction in the metal phase ') will give a good approximation of log K_O, even in systems where $x = N_{Fe^{2+}} + N_{Mn^{2+}}$ deviates considerably from unity, and the activity coefficients show marked deviations from ideality.

This is in agreement with the results of Krings and Schackmann's investigations[2] of the variation of the manganese distribution in pure basic oxides with the addition of lime. When their data are recalculated using ionic fractions, the results show that the dependence of the manganese distribution constant on $N_{Ca^{2+}}$ is very small (*see* Fig. 1).

Previously reported extrapolations[1] of the logarithm of the equilibrium constant for the manganese distribution, log K_{mix}* to $N'_{O^{2-}} = 1$ in a mixture of different anions and cations are, within the accuracy of the measurements, in agreement with the equilibrium constant determined from investigations of the same reaction in relatively pure FeO–MnO slags.

It may be demonstrated in the same way that the influence of other anions on an anion-exchange equilibrium is a second-order effect compared with the influence of the cations.

When the equilibrium constant for the reaction

$$2\underline{P} + 5\underline{O} + 3CaO\ (liq) = Ca_3PO_4\ (liq)$$

calculated from Bookey's[3] experimental data for the same reaction in the solid states, is compared with the value obtained by extrapolation from a slag, it may be shown that the influence of other anions (such as SiO_4^{4-}, etc.) on this anion equilibrium is very small.[4]

This demonstrates that the coefficients obtained by extrapolation in the additive formula of log K' for cation or anion equilibria may ordinarily be expected to correspond to the equilibrium constants of the pure unmixed systems.

From this formula it is obvious that by experimental investigations of pure cation equilibria it should be possible to avoid contamination with other anions, whereas contamination with other cations is not so harmful (and *vice versa* for anion equilibria); *e.g.*, it is better to measure the pure equilibrium

$$FeO\ (liq) + \underline{Mn} = \underline{Fe} + MnO\ (liq)$$

using thermocouples encased in magnesia tubes rather than those encased in silica tubes. Small amounts of Mg^{2+} ions in the melt will be a second-order effect compared with the influence of SiO_4^{4-} ions.

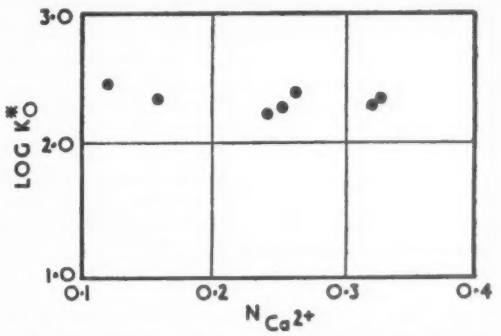


Fig. 1—Dependence of manganese distribution on the ionic fraction of calcium. From Krings and Schackman's[2] data ; temperature 1550–1560° C.

In this equilibrium melt there will always be some trivalent iron present, which will affect the equilibrium constant in a way similar to SiO_4^{4-} ions, because trivalent iron is most likely to be present as ferrite anions in the more basic melts.

To study these effects more closely, it is proposed to consider the experimental data of Chipman, Gero, and Winkler[5] on the manganese distribution. Their excellent investigations were made with liquid steel under simple slags consisting of the oxides of iron and manganese with small amounts of impurities. The experimental data are recalculated to ionic fractions and given in Table I.

As the equilibrium constant for the manganese distribution is higher in both the pure orthosilicate melt and the hypothetical pure ferrite melt than in the hypothetical pure oxide melt, the constant obtained from the measurements of Chipman *et al.* will be somewhat higher than it would be in a melt of pure oxides. Because the constants K_{SiO_4} and K_{FeO_4} in the additive formula for the manganese distribution are approximately known, their logarithms being 3·1 and 3·0 at 1600° C., respectively, a correction may be applied for the influence of both silica and trivalent iron.

The logarithm of K'_O is calculated from the following formula:

$$\log K'_O = \frac{1}{N'_{O^{2-}}}\left[\log K'_{mix} - (3{\cdot}1\ N'_{SO_4^{4-}} + 3{\cdot}0\ N'_{FeO_4^{4-}})\right]$$

Table I

CALCULATED VALUES OF K_O^{Mn}

Derived from experimental data of Chipman, Gero, and Winkler[5]

Heat No.	Temp., °C.	Slag Analysis: Cations (Ionic Fractions) Fe^{2+}	Mn^{2+}	Mg^{2+}	Ca^{2+}	Slag Analysis: Anions (Equivalent Fractions) $N'_{O^{2-}}$	$N'_{SiO_4^{2-}}$	$N_{FeO_4^{5-}}$	Metal Analysis, wt.-% (P_{Mn})	Observed K^{Mn}_{mix}	Observed $\log K'_{mix}$	Corrected $\log K'_O$	Corrected K_O^{Mn}
D–65–44	1568	0·657	0·317	0·012	0·014	0·841	0·076	0·083	0·118	407	2·61	2·53	338
D–56–16	1587	0·610	0·361	0·021	0·007	0·837	0·092	0·071	0·17	347	2·54	2·44	275
D–65–26	1598	0·595	0·386	0·002	0·017	0·897	0·042	0·061	0·18	360	2·56	2·50	316
D–65–32	1638	0·537	0·409	0·027	0·026	0·881	0·066	0·053	0·27	281	2·45	2·38	240
D–65–34	1706	0·616	0·352	0·022	0·010	0·907	0·032	0·061	0·29	197	2·29	2·21	162
D–65– 6	1743	0·579	0·404	0·011	0·006	0·908	0·046	0·046	0·38	183	2·26	2·18	151

and values are given in the penultimate column of Table I; $\log K'_{mix}$ is the experimental value obtained by Chipman *et al.* at different temperatures. The temperature variations of K_{SiO_4} and K_{FeO_4} are neglected, but the influence of these on the correction term is most likely to be very small, whilst $N'_{SiO_4^{4-}}$ and $N'_{FeO_4^{4-}}$ are small in relation to $N'_{O^{2-}}$. It may be concluded that these calculations give the correct magnitude of the effect of silica and trivalent iron on the manganese equilibrium constant in the measurements of Chipman *et al.*[5]

Acknowledgment

The author is greatly indebted to Professor Dr. H. Flood for valuable discussions.

References

1. H. Flood and K. Grjotheim: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 64–70.
2. W. Krings and H. Z. Schackmann: *Zeitschrift für anorganische und allgemeine Chemie*, 1932, vol. 206, pp. 337–355.
3. J. B. Bookey: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 61–66.
4. H. Flood, T. Förland, and K. Grjotheim: Symposium on the Physical Chemistry of Melts, pp. 46–62 : 1953, London, Institution of Mining and Metallurgy.
5. J. Chipman, J. B. Gero, and T. B. Winkler: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 341–345; *J. Met.*, 1950, vol. 2, Feb.

Absorptiometric Determination of Molybdenum in Iron and Steel

By the Methods of Analysis Committee

SYNOPSIS

The absorptiometric procedure for the determination of molybdenum, based on the formation of a molybdenyl thiocyanate compound, has been further investigated and many aspects of the reaction have been critically examined.

Formation of coloured reaction products which interfere, including those of iron, tungsten, cobalt, vanadium, and copper, has been either suppressed or compensated for by means of correction graphs. Titanium, added to the final solution, catalyses the reaction and ensures complete reduction of the ferric thiocyanate.

The method has been successfully applied to a variety of iron-base alloys; the importance of obtaining complete decomposition of samples is particularly emphasized. 992

A survey of the literature reveals a variety of procedures for the absorptiometric determination of molybdenum, with a marked preference for the method based on the molybdenum thiocyanate reaction. In special cases (*e.g.*, where only a very small sample is available) the colorimetric procedure using toluene-3-4-dithiol[1] is favoured.

In the examination of tungsten-bearing steels, existing gravimetric and colorimetric methods have not proved entirely successful, owing to co-precipitation of molybdenum with tungsten. The method proposed by the B.I.S.R.A. Pig Iron, Carbon and Low Alloy Steels Analysis Sub-Committee,[2] published as B.S. 1121: Part 26: 1952, only provides for steels containing up to 0·5% of tungsten. A relatively rapid and reliable method to cover the wide variety of molybdenum-containing steels is therefore required.

The investigation outlined in this report was made by the Physico-Chemical Methods of Analysis Sub-Committee of the Metallurgy (General) Division of B.I.S.R.A.,* with the object of providing a suitable absorptiometric procedure to meet these requirements. Use of the Hilger photoelectric absorptiometer is implied throughout the whole of the experimental work. The Committee recognizes the valuable assistance given by many other analysts during the period of the investigation.

Paper MG/D/271/53 of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 12th May, 1954.

* The constitution of the Sub-Committee at 31st March, 1953, was: Mr. H. G. Short (*Chairman*), N.P.L.; Mr. D. Bell, Colvilles Ltd.; Mr. H. Cox, Metropolitan-Vickers Electrical Co., Ltd.; Mr. E. Dyke, Brown-Firth Research Laboratories; Mr. F. E. Eborall, Geo. Senior and Sons, Ltd.; Mr. L. E. Gardner, Edgar Allen and Co., Ltd.; Mr. C. H. R. Gentry, Philips Electrical Ltd.; Mr. H. Groom, Bragg Laboratory, N.O.I.D.; Mr. S. Harrison, Kayser, Ellison and Co., Ltd.; Mr. G. Padget, United Steel Companies, Ltd.; Miss R. Presser, formerly of B.C.I.R.A.; Miss L. E. Sparrow, G.K.N. Group Research Laboratories; Mr. J. O. Lay (*Secretary*), B.I.S.R.A.

THE MOLYBDENUM THIOCYANATE REACTION

When determining molybdenum in ferrous alloys, the intensity of this colour reaction is a function of the amount of iron present; furthermore, the extent of the reduction of the ferric thiocyanate is influenced by the amount of molybdenum present. In the presence of a small amount of molybdenum, a small but variable quantity of ferric thiocyanate is unreduced. This variation is of such an order as to invalidate all values below about 0·05% Mo.

During development of the recommended procedure, with a view to overcoming these difficulties, several

modifications were tried, including the use of a large excess of stannous chloride, extraction with an organic solvent, and catalysing the reaction with added Ti. These modifications are separately referred to later.

SOLUTION OF THE SAMPLE

Molybdenum and certain other metals associated with highly alloyed steels form refractory carbides which are difficult to decompose with acids. Every precaution must therefore be taken to ensure complete solution of the sample. These remarks apply especially to high-speed and high C–Cr die steels.

A good solvent for most steels is a suitable mixture of sulphuric and phosphoric acids. Unfortunately, solutions of tungsten-bearing steels subsequently present difficulties due to the formation of soluble phosphotungstic acids. These give rise to tungsten thiocyanates, interfering coloured compounds which cannot be easily eliminated or accurately allowed for by means of a correction graph. Phosphoric acid also promotes the hydrolysis of tin salts with the formation of undesirable turbid solutions. For these reasons use of this solvent was discontinued.

Perchloric acid is an excellent solvent for most steels, and solution in this way, followed by reduction with sulphurous acid, was considered. Other modifications examined included the formation of soluble citric-acid–tungsten complexes; this reaction was later used in the recommended procedure.

The solvent finally chosen proved satisfactory over a wide range of steels. Using this combined hydrochloric–nitric acid solvent it is necessary to ensure adequate expulsion of nitric acid to achieve complete reduction of ferric thiocyanate at a later stage in the recommended procedure.

REAGENTS

A comparison has been made between high-quality ammonium molybdate and pure molybdenum wire as standards for calibration purposes. The conclusion was that either could be used in making up the standard solution.

Ammonium thiocyanate is recommended in preference to the corresponding sodium salt since the former is less deliquescent; use of the potassium salt is precluded owing to the formation of an insoluble perchlorate. The method will tolerate small variations arising from different batches of thiocyanate.

EXPERIMENTAL

The problem in the early stages of the investigation resolved itself into two parts, since it appeared that the determination of molybdenum below about 0·1% would require special consideration.

Experimental work was begun along these lines, but later a comprehensive method was developed which covered the entire range of Mo contents with an accuracy acceptable for most purposes.

The first series of results are considered to be of sufficient interest to warrant inclusion in this report (*see* Table I).

MOLYBDENUM CONTENTS BELOW 0·1%

Several procedures specially suitable for the determination of small amounts of molybdenum were examined, including one recommended by the Residual Elements Panel of the Standard Methods of Analysis Sub-Committee of the Iron and Steel Institute.* This procedure recommends a relatively high concentration of stannous chloride to ensure maximum reduction of the ferric thiocyanate with reasonable rapidity. A straight-line graph was obtained under these conditions and, apart from interference due to copper at a relatively low concentration, the method showed a marked advance in the determination of small amounts of molybdenum.

Table I

RESULTS BY BUTYL ACETATE EXTRACTION

Operator	Molybdenum, % MGS/65	MGS/79
1	0·021	0·042
2	0·024	0·040
3	0·019	0·038
4	0·018	...
5	0·018	0·037
6	0·019	0·039
7	0·022	0·041
Average	0·020	0·040
Range	0·006	0·005

An extension of this thiocyanate procedure involved the use of an organic solvent. Using this extraction procedure and completing the determination absorptiometrically, a high degree of accuracy was achieved. There was no background interference, little trouble from cuprous thiocyanate precipitation, and only slight interference from unreduced ferric thiocyanate. Extraction of traces of tungsten thiocyanate did occur, but, although such interference was not linear, it could be corrected for. The molybdenum graph itself followed a smooth curve.

The results given in Table I were obtained using the molybdenum thiocyanate procedure just referred to, including extraction with *n*-butyl acetate. The light source was a mercury-vapour lamp used in conjunction with Wratten No. 74 and Calorex H503 filters. Sensitivity in the lower molybdenum ranges can be increased by using a tungsten-filament light source with Ilford 602 and Calorex H503 filters.

MOLYBDENUM CONTENTS ABOVE 0·1%

The first method examined was a composite method embodying the best features of methods in regular use by individual Sub-Committee members. A phosphoric–sulphuric acid mixture was used to dissolve the sample, and perchloric acid was added to stabilize the molybdenum thiocyanate colour.

When this procedure was applied to low-alloy steels, the results were excellent, but its application to the more highly alloyed steels gave poor reproducibility. In addition, tungsten interfered and correction by the use of a calibration graph was unsatisfactory; there was also some evidence that tungsten interference was dependent on the molybdenum content. Extension of the method to higher molybdenum contents (up to 5%) gave a wide spread of results, and these additional difficulties led to use of this procedure being discontinued.

The efficiency of titanium in catalysing the

* This Sub-Committee was in operation until 1946, when the present B.I.S.R.A. Methods of Analysis Committee was formed and took over work then in progress.

Table II
COMPOSITION OF SAMPLES EXAMINED

	C, %	Mn, %	Ni, %	Cr, %	W, %	Co, %	V, %
MGS/48	1·0	...	...	4·5	22	12	1·5
/50	...	...	...	4·6	6·7	0·7	1·4
/65	1·1	1·5	...	0·2	0·4	...	...
/73	...	...	10	18	...	...	...
/79	1·0	0·5	...	1·5	0·7	...	...
/96	0·4	1·4	...	...	...	...	...
/97	0·4	0·5	0·5	1·0	...	...	...
/98	0·8	0·3	...	4·5	18	11	1·5
/141	...	...	9	18	...	...	...
/168	1·5	0·4	...	11·5	...	...	...
/171	Pure iron and molybdenum : nominal Mo, 0·5%						
/172	" " " " : nominal Mo, 5·0%						
/180	0·9	0·3	...	4·5	18·5	5	1·0

reduction of ferric thiocyanate had been observed during work on a method for the determination of molybdenum in titanium metal.[3] This principle was incorporated into a procedure recommended for trial, since it appeared to have distinct advantages and avoided an undesirable organic extraction.

THE RECOMMENDED PROCEDURE

The catalytic action of titanium was so successful that addition of this metal, at an appropriate stage, is included in the procedure. Provision is also made for the presence of tungsten.

By suitable modification, the procedure is applicable to all steels containing molybdenum up to about 5%. The intensity of the fully developed colour is sensitive to temperature variation, necessitating a close control of the temperature of solutions before optical densities are determined. The colour is stable for at least 30 min. after development at a fixed temperature.

INTERFERING METALS

Cobalt

Salts of this metal form coloured thiocyanates which must be corrected for by means of a suitable graph; *e.g.*, it has been shown that 1% of cobalt is equivalent to about 0·005% of molybdenum.

The use of citric acid in the presence of tungsten appears to promote slight atmospheric oxidation of cobaltous salts, which gives rise to colours of variable intensity. This is overcome by addition of a small volume of sulphurous acid at an appropriate stage in the procedure.

Vanadium

Vanadium salts introduce slight interference due to the formation of a yellow thiocyanate. This interference is about twice that of cobalt and may be compensated for by means of a suitable graph.

Copper

When present in excess of about 0·4%, copper is precipitated as cuprous thiocyanate; this must be removed by filtration.

Tungsten

Owing to the disadvantages associated with phosphoric acid in the presence of tungsten, removal of this metal, after hydrolysis from a hydrochloric acid solution, was considered. Removal of tungsten in this way necessitated the examination of all residues for molybdenum. This was done by fusing the ignited residue with sodium carbonate and extracting the cold melt with a solution of citric acid. The extract, after acidification, was examined for molybdenum by a thiocyanate procedure. Difficulties were experienced owing to the sensitivity of the procedure to small variations in traces of residual iron. Traces of vanadium, similarly occluded in the tungsten precipitate, also gave erratic molybdenum recoveries.

At this stage the procedure described in the Appendix (Note 2) was applied. Using the ammonium citrate modification recommended, tungsten is retained in solution, and interference from this metal is completely eliminated without any apparent influence on the characteristic molybdenum colour.

APPLICATION

The procedure has been applied to a wide range of steels. Table II gives an indication of some of these and Table III shows the results obtained, many of which closely confirm those reported using B.S. 1121: Part 26: 1952.

References

1. J. E. Wells and R. Pemberton: *Analyst*, 1947, vol. 72, pp. 185–188.
2. Methods of Analysis Committee: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 75–80.
3. Internal information supplied by co-operating laboratories.

APPENDIX
Recommended Method

Reagents Required

Acid Titanium Mixture—Dissolve 1·5 g. of pure titanium metal in 200 ml. of sulphuric acid (10% vol./vol.), cool, and add to a mixture of 200 ml. of water, 320 ml. of perchloric acid (sp. gr. 1·54), and 230 ml. of sulphuric acid (sp. gr. 1·84). Cool and dilute to 1 l.

Sulphuric Acid (50% vol./vol.).

Ammonium Thiocyanate (20%).

Stannous Chloride (10%)—Dissolve 10 g. of stannous chloride ($SnCl_2.2H_2O$) in 5 ml. of hydrochloric acid (sp. gr. 1·16), warming if necessary, cool, and dilute to 100 ml. with water.

Table III

RESULTS ON SAMPLES BY RECOMMENDED METHOD, % Mo

Analyst	MGS/48	MGS/50	MGS/65	MGS/73	MGS/79	MGS/96	MGS/97	MGS/98	MGS/141	MGS/168	MGS/171	MGS/172	MGS/180
1	0·66	4·17	0·016	1·28	0·036	0·27	0·22	0·99	2·68	0·77	0·51	5·30	0·62
2	0·68	...	0·020	1·28	0·030	0·24	0·21	0·99	2·58	...	0·49	5·23	0·61
3	0·68	4·12	0·018	1·31	0·034	0·26	0·21	1·01	2·66	0·79	0·50	5·30	0·65
4	0·66	4·17	...	1·29	...	0·25	0·20	1·02	2·63	0·81	0·50	5·28	0·64
5	0·66	4·14	...	1·25	...	0·27	0·20	0·99	2·61	0·77	0·49	5·31	0·63
6	0·63	4·16	0·028	1·31	0·040	0·24	0·21	0·97	2·66	0·83	0·47	5·20	0·61
7	0·63	4·21	...	1·29	...	0·25	0·21	0·99	2·64	0·79	0·48	5·27	0·62
8	0·62	4·22	0·025	1·25	0·031	0·25	0·22	0·99	2·62	0·80	0·49	5·19	0·60
9	0·68	...	0·020	1·27	0·030	0·26	0·21	1·01	2·62	...	0·48	5·28	0·61
10	...	4·10	...	1·27	...	0·26	0·21	1·02	2·58	...	0·50	5·25	...
11	0·65	4·15	0·025	1·30	0·036	0·27	0·21	0·99	2·67	0·82	0·50	5·28	0·63
Average	0·66	4·16	0·022	1·28	0·034	0·26	0·21	1·00	2·63	0·80	0·49	5·27	0·62
Range	0·05	0·12	0·012	0·06	0·010	0·03	0·02	0·05	0·10	0·06	0·04	0·12	0·05

Procedure

Dissolve 0·5 g. of sample (Note 1) in 20 ml. of hydrochloric acid (sp. gr. 1·16), digest (Note 2), add 5 ml. of nitric acid (sp. gr. 1·42), and boil. Add 10 ml. of sulphuric acid (50% vol./vol.), evaporate to fumes, and cool (Note 3). Add 15 ml. of sulphuric acid (50% vol./vol.) and 40 ml. of water, transfer to a graduated flask, and dilute to 100 ml.

Filter a portion of the liquid through a dry filter paper into a dry beaker, discarding the first few ml., pipette two 20-ml. fractions into 50-ml. graduated flasks (*a*) and (*b*), and treat as follows:

(*a*) *Test Solution*—Add 10 ml. of acid titanium mixture, 5 ml. of ammonium thiocyanate (20%), and mix. Add 10 ml. of stannous chloride (10%), mix at once, dilute to the mark, mix again, and allow to stand for 15 min. at 20 ± 2° C.

(*b*) *Compensating Solution*—Add 10 ml. of acid titanium mixture and 10 ml. of stannous chloride (10%). Mix, dilute to the mark, mix, and allow to stand for 15 min. at 20 ± 2° C.

Obtain the difference reading between the optical density of the test solution (Note 4) and the compensating solution and read the percentage molybdenum from a calibration curve prepared under similar conditions, corrected if necessary for cobalt and vanadium (Note 5). Suitable conditions with the Hilger photoelectric absorptiometer are:

Mercury-vapour lamp
Wratten No. 74 and Calorex No. H503 filters
0·5–4-cm. cells (Note 6).

Calibration

Solutions Required

Molybdenum solution *A*: dissolve 0·9201 g. of ammonium molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$) in water and dilute to 1 l.; 1 ml. = 0·0005 g. of molybdenum.

Molybdenum solution *B*: dilute 100 ml. of solution *A* to 1 l.; 1 ml. = 0·00005 g. of molybdenum.

Procedure

To several 0·5-g. samples of pure iron add measured volumes of solutions *A* and *B* to cover the molybdenum range required and treat as in the section on procedure. Plot difference readings against percentage molybdenum to prepare a calibration graph.

Notes

(1) For molybdenum contents above 2·6%, a reduced sample weight made up to 0·5 g. with pure iron may be used.

(2) For samples containing alloying amounts of tungsten, prolong the digestion until a clean solution is obtained and oxidize dropwise with nitric acid (sp. gr. 1·42). Add 10 ml. of sulphuric acid (50% vol./vol.) and evaporate to fumes, fume gently for about 2 min., add 30 ml. of water, and boil until all sulphates are re-dissolved. Cool, add 10 ml. of ammonium citrate (50%) and 1 ml. of sulphurous acid. Make ammoniacal and add a sufficient excess (about 3–4 ml.) to take tungstic acid into solution, warming if necessary. Neutralize the solution with sulphuric acid (50% vol./vol.), using bromocresol purple indicator paper, and add 25 ml. in excess. Cool, filter if necessary, dilute to 100 ml. in a graduated flask, and continue as in the second paragraph of the section on procedure.

In the examination of certain steels of high niobium content, the insoluble residue may contain small amounts (up to 0·02%) of molybdenum. For the highest accuracy the residue should be ignited at a temperature not exceeding 550° C. and fused with potassium carbonate, molybdenum being determined colorimetrically on an extract of the fusion.

(3) Most carbide residues respond to oxidation with nitric acid followed by fuming. Certain classes of high carbon–chromium alloys of the tool and die steel class leave large residues of very resistant carbide which are not always completely decomposed by this treatment. In such cases, dissolve the sample in sulphuric acid alone (25 ml. of sulphuric acid (50% vol./vol.) + 40 ml. of water) and digest at incipient boiling for an extended period before oxidation with nitric acid. Alternatively, the solution in sulphuric acid may be evaporated to fumes in the ferrous condition, oxidized with nitric acid after extracting the sulphates, and the evaporation to fumes repeated.

(4) In the case of steels containing more than 0·4% of copper, cuprous thiocyanate may be precipitated. This can be removed by filtration through a dry filter paper.

(5) The corrections required are: 1% C ≅ 0·005% Mo; 1% V ≅ 0·01% Mo.

(6) Using the 1-cm. cell, replicate determinations should lie within ± 0·03% Mo. Greater accuracy may be obtained, if necessary, in the limited range 0–0·10% Mo by using the following instrument conditions:

Tungsten lamp
Ilford 602 and Calorex H503 filters
4-cm. cells.

The Sulphur Distribution Reaction between Blast-Furnace Slag and Metal

By J. Taylor, M.Sc., Ph.D., and J. J. Stobo, B.Sc., A.R.T.C.

SYNOPSIS

The sulphur distribution between blast-furnace-type slag and metal has been studied. Evidence is submitted to show that the reaction can come to equilibrium with carbon whilst the oxygen potential of the slag is still greater than that corresponding to C–CO. A reaction mechanism to fit this observation is suggested. The sulphur distribution ratio is shown to be independent of temperature in the region 1425–1550° C., which is ascribed to change in the activity of the CaO of the slag. The effect of FeO on the ratio is minimized by a decrease in the activity coefficient with increasing concentration, but otherwise is straightforward. Equilibrium values of the distribution ratio are shown to be about one-half to one-third of those obtained in practice. Estimates of the oxygen potential of slag from three furnaces gave values corresponding to the observed sulphur distribution ratio. From this it is concluded that reaction between coke and the FeO (MnO) of the slag is a most important limiting factor in the distribution ratios attained in practice. 980

EQUILIBRIUM studies of the sulphur partition reaction between blast-furnace-type slag and metal have been made by Chipman and co-workers.[1–3] From the results of these investigations it appeared that in normal blast-furnace operation the sulphur distribution ratios were far below the equilibrium values.

Two points in connection with these experiments required further clarification. One was that the silicon contents of the metal, particularly in contact with the more acid slags, were much higher than is usual in pig iron. The effect on the measured distribution ratios was unknown. This has since been established by the work of Morris and Williams[4] and Morris and Buehl,[5] who determined the effect of carbon and silicon on the activity coefficient of sulphur in iron. Recently Sherman and Chipman[6] have determined the effect of a number of solutes on the activity coefficients of sulphur in iron solution. They also elaborated a method suggested by Morris and Buehl whereby activity coefficients in ternary and more complex mixtures could be combined. It is therefore possible to recalculate experimental values of the sulphur distribution for normal pig-iron compositions. The difference between these values and those obtained in practice is then much reduced.

The other doubtful point was the exact nature of the equilibrium measured. The experiments were carried out in carbon crucibles and it was considered that equilibrium was established for the oxygen potential of C–CO at 1 atm. pressure. This seemed probable but analyses of the slags for FeO caused some difficulty. The first analyses of Hatch and Chipman[1] were of the order 0·2% FeO. A number of the slags were re-analysed after a more rigorous magnetic separation and gave FeO values of about 0·03%. Since a_{FeO} in equilibrium with a carbon-saturated iron–carbon binary alloy at 1500° C. and 1 atm. CO is 0·024%, it appeared probable that the equilibrium was indeed that corresponding to the oxygen potential of C–CO. However, Grant, Kalling, and Chipman[2] in a subsequent paper reported FeO values of about 0·1%. Also, Filer and Darken[7] from a similar carbon-crucible experiment and after magnetic separation gave an FeO value of 0·23%.

There remained therefore some doubt whether the FeO in the slag had come into equilibrium with carbon in these experiments. The most commonly accepted mechanism of the desulphurization reaction is:

$$[FeS] = (FeS) \quad \ldots\ldots(1)$$

$$(FeS) + (CaO) = (CaS) + (FeO) \quad \ldots\ldots(2)$$

$$C + (FeO) = Fe + CO \quad \ldots\ldots(3)$$

According to this series of reactions if the equilibrium is approached from the sulphur-in-metal side the distribution ratio cannot rise above that corresponding to the FeO content of the slag. The exact FeO content of the slag appeared therefore to be of great significance.

The FeO content of operational slags is equally important. Sulphur distribution ratios are only one-half to one-third of those derived from the results of Hatch and Chipman. Assuming that these do relate to the oxygen potential of C–CO, it can be said that equilibrium with carbon is not attained in the blast-furnace. That may be because either the equilibrium slag–metal or slag–carbon, or both, is not realized. It would be of great interest if it could be established how close these equilibria are approached. If the value of 0·03% FeO is taken as approximating to that in equilibrium with carbon and if the activity coefficient of FeO in dilute slag solution does not vary much, the observed sulphur distribution values would correspond to FeO values of about 0·05–0·10%. These are much lower than those normally reported, which would imply that the sulphur distribution ratio is better than that corresponding to the slag–metal equilibrium. But analysis of slag for FeO is notoriously unsatisfactory and no such deduction may be drawn. Moreover, even if accurate analyses could be made, the uncertainty regarding the FeO values at equilibrium remains.

Manuscript first received on 31st October, 1953, and in its revised form on 11th June, 1954.

Dr. Taylor and Mr. Stobo are with the Metallurgy Department of the Royal Technical College, Glasgow.

The object of the present investigation was to confirm that the sulphur equilibrium measured in carbon-crucible experiments was that for the C–CO oxygen potential and to measure the effect of increasing FeO on that equilibrium.

EXPERIMENTAL WORK

The experiments were carried out in a molybdenum-wound furnace in which was a 2-in. mullite tube. Temperatures were measured with a Pt/Pt–13% Rh thermocouple placed immediately below the crucible. The furnace atmosphere was that produced by reaction of air and carbon at 1 atm. pressure. No difference could be observed when an atmosphere of pure carbon monoxide was used: this was to be expected since the reaction pressure is that of carbon monoxide produced at the slag–metal interface.

The first series of experiments was carried out in graphite crucibles when 100 g. of Armco iron and 50 g. of slag constituents were charged to the crucible and brought up to temperature. Sulphur was added either as FeS to the molten metal or as CaS along with the solid slag. There was always a considerable loss of sulphur (about 30%), some of which was absorbed by the crucible. Allowance was made for this in calculating the sulphur charge. The approach to equilibrium was checked by sampling and analysing the metal for sulphur; the time to reach equilibrium was 5–12 hr. Final metal and slag samples were then taken for complete analysis.

When attempting to study the effect of FeO on the equilibrium the problem was to find a refractory material capable of withstanding both iron and slag. It had to be accepted that the slag would dissolve the refractory until saturation was reached and in these circumstances alumina was chosen. The type of crucible used (Fig. 1) was of alumina lined with molybdenum sheet and enclosing an inner alumina crucible. Originally it was hoped that by fixing the slag–metal interface as in the diagram, pick-up of alumina might be sufficiently minimized that slags not saturated with alumina could be used. This hope was not realized but the use of the crucible was continued with alumina-saturated slags.

These crucibles were charged with high-carbon iron made by melting Armco iron in a graphite crucible and casting in a size to fit the inner alumina crucible. When approaching the equilibrium from the metal side, sulphur was added as FeS in the pre-melting stage. When approaching from the slag side CaS and FeO were added during the experiment as required. The slag was made to a composition of 35% Al_2O_3, 34% CaO, and 31% SiO_2. Solution of alumina from the crucible brought the alumina content up to about 42%, the saturation value at 1500° C. Attempts to sample metal at intervals as in the carbon-crucible experiments were not very successful, chiefly owing to the smaller diameter. The attainment of equilibrium was judged in this series by carrying out experiments for varying periods of time; at the end of the run the slag was sampled molten but the metal was allowed to freeze in the crucible. Both slag and metal froze rapidly and it is most unlikely that any appreciable shift in the equilibrium occurred in cooling down. Drillings were taken from the metal for analyses and although several samples were analysed for molybdenum and aluminium none was detected. Segregation during freezing of the metal was also considered but again none could be detected.

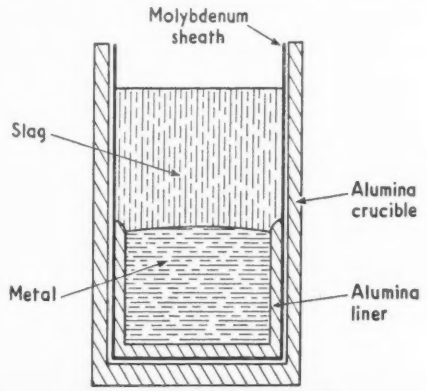


Fig. 1—Crucible assembly

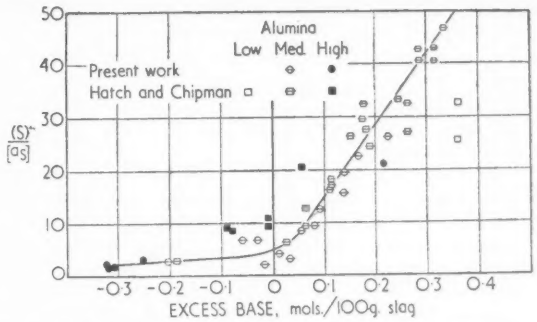


Fig. 2—Desulphurization ratio and slag basicity

Results of Experiments in Carbon Crucibles

In Fig. 2 the distribution ratio (%S)/[a_S] is plotted against the measure of slag basicity used by Hatch and Chipman, *viz.*,

$$\text{Excess base} = (\text{CaO} + \tfrac{2}{3}\text{MgO}) - (\text{SiO}_2 + \text{Al}_2\text{O}_3) \quad \text{moles per 100g. slag.}$$

These authors' results for a similar slag sulphur, *i.e.*, 1·5%, converted to the sulphur-activity basis, are also included. In general, there is very good agreement, particularly for the medium-alumina slags. Values for high-alumina slags lie to the right and for low alumina to the left of the mean curve, suggesting that the effect of alumina as an acid is overemphasized in the expression for excess base. When plotted on this basis no temperature effect can be observed over the range covered, *i.e.*, 1425–1550° C. The increase in the (%S)/[%S] ratio with temperature shown by Hatch and Chipman is entirely due to the increase in carbon and silicon at the higher temperatures raising the activity coefficient of sulphur in metal solution.

The excellent agreement between the two investigations confirms that the measured equilibrium is the

same. It also provides a useful check of the reliability and usefulness of the activity coefficients. The analysed FeO values (Table I) in the present case, however, were of the order 0·1–0·3%. Moreover, they remained constant after repeated grinding and magnetic separation with a strong electromagnet.

The question of the FeO content of these slags is unsatisfactory because no method has yet been devised for the analytical separation of FeO and metallic iron. There is therefore no independent check on the efficiency of magnetic separation. In the absence of sulphur the separation appears to be reliable and gives consistent results, but there is reason to suppose that sulphur interferes in some way with the separation. The values quoted in Table I are probably somewhat high because of this. To clarify this point three of the experiments quoted in Table I were duplicated, except that no sulphur was added. For similar silicon concentrations to those shown, the FeO concentrations were 0·11, 0·12, and 0·09%. Similar values were obtained in experiments on the silicon distribution between slag and metal at low silicon concentrations. But it was also shown that the analysed FeO value steadily fell to 0·02% as the silicon content rose towards the equilibrium value, *i.e.*, low values could be obtained after magnetic separation. Furthermore, with a lime–alumina slag the FeO value fell to 0·02% after 2–3 hr.

Apparently the FeO content of the slag is the product of a dynamic equilibrium between the reactions

$$(SiO_2) + 2Fe = \underline{Si} + 2(FeO) \quad \ldots\ldots(4)$$

and

$$\underline{C} + (FeO) = Fe + CO \quad \ldots\ldots(5)$$

When the silicon concentration in the metal is small the resulting FeO concentration is about 0·1% and there is strong presumptive evidence that the true FeO concentration for most of the experiments listed in Table I is of that order. Therefore, whilst the sulphur distribution is that corresponding to the C–CO oxygen potential the FeO content corresponds to a higher oxygen potential. This is obviously impossible according to the usual mechanism, shown in reactions (1), (2), and (3). The alternative is to regard desulphurization as an interface reaction, as already suggested by Rosenqvist,[8] *viz.*,

$$\underline{S} + O^{2-} = S^{2-} + \underline{O} \quad \ldots\ldots(6)$$

According to this scheme the distribution ratio is controlled by the oxygen content of the metal at the slag–metal interface and not by the FeO of the slag.

Wagner[9] has studied reactions of a similar type between solid reactants and shown that they proceed by the deposition of one element at the phase boundary and the solution of the other, with the simultaneous transfer of electrons. By analogy, sulphur atoms transfer from metal to slag and become ionized by acquiring the two electrons given up by the oxygen ions which simultaneously proceed from slag to metal. This oxygen can then react with carbon or can diffuse back across the interface, but in the latter case it must be accompanied by iron in the same proportion as in FeO :

$$\underline{C} + \underline{O} = CO \quad \ldots\ldots(7)$$

or

$$\underline{Fe} + \underline{O} = Fe^{2+} + O^{2-} \quad \ldots\ldots(8)$$

It can be imagined that when reaction (6) is vigorous, $\underline{O}$ forms more rapidly than its removal by reaction (7) and it diffuses into the slag as FeO. As reaction (6) approaches equilibrium, the oxygen content of the metal is controlled more and more by reaction (7) and FeO diffuses back from slag to metal until overall equilibrium is established. Derge, Philbrook, and Goldman[10] observed that during the transfer of sulphur from metal to slag the FeO content of the slag first increased and then decreased as the reaction progressed. This they considered to be proof that the commonly assumed mechanism (reactions (1), (2), and (3)) is correct. The proposed mechanism could equally well explain the observation.

But this mechanism still does not account for the

Table I

RESULTS OF EXPERIMENTS IN CARBON CRUCIBLES

Expt. No.	Time, hr.	Temp., °C.	Slag Analysis, wt.-%			FeO, %	S, %	Excess Base, moles/100 g. slag	Metal Analysis, wt.-%			(% S)/[% S]	f_S	(S)/[a_S]
			CaO	SiO_2	Al_2O_3				Si	C	S			
3	7	1550	46·1	35·1	19·1	...	1·13	+0·055	0·88	...	0·022	51	6	8·56
5	7	1550	43·0	36·8	19·3	0·10	1·03	−0·029	0·94	...	0·027	38	6	6·36
6	9	1500	42·4	38·2	18·8	...	1·67	−0·061	0·22	...	0·042	40	6	6·63
7	12½	1450	45·1	38·2	16·1	0·11	1·64	+0·011	0·10	4·92	0·077	21	5·2	4·07
8	9	1550	51·1	32·0	16·1	...	1·25	+0·225	...	...	0·008	156	6	26·1
9	9	1500	40·0	39·9	20·9	0·09	1·72	−0·156	0·38	4·85	0·117	15	5·5	2·66
11	7	1550	43·7	38·4	16·0	0·27	1·37	−0·020	0·50	4·90	0·108	13	5·8	2·20
12	7	1500	45·4	36·6	16·0	0·30	1·29	+0·031	0·13	5·08	0·075	17	5·7	3·04
23	6½	1500	29·9	24·5	44·7	...	1·17	−0·323	0·78	3·94	0·200	6	3·9	1·52
26	7	1500	30·1	28·0	40·3	0·18	1·57	−0·253	2·62	4·26	0·064	25	7·7	3·2
40	7	1500	30·6	25·2	44·0	0·12	1·13	−0·310	0·46	4·94	0·110	10	5·9	1·75
42	9	1500	30·1	26·3	42·6	0·19	1·13	−0·326	0·48	4·60	0·143	8	4·9	1·60
43	7	1500	48·0	32·4	18·5	0·18	1·68	+0·136	0·56	5·09	0·017	100	6·5	15·3
44	7	1500	46·5	34·0	18·7	0·21	1·56	+0·080	0·51	4·92	0·028	56	5·9	9·51
47	10	1450	46·9	34·1	18·2	0·29	1·30	+0·090	0·67	5·00	0·016	81	6·4	12·7
53	7	1500	48·5	34·2	16·6	0·06	1·74	+0·137	0·34	5·08	0·015	116	6·0	19·3
59	5	1500	49·1	34·4	14·6	0·12	1·75	+0·162	3·82	4·03	0·008	219	9·7	22·6

fact that reactions (6) and (7) can come to equilibrium whilst the FeO content of the slag remains above that corresponding to equilibrium with carbon. The phenomenon is associated with the continued reduction of silica. This reaction can be pictured as proceeding in an analogous fashion to the desulphurization reaction, *viz.*,

$$2[Fe] + Si^{4+} + 2O^{2-} = [Si] + 2Fe^{2+} + 2O^{2-} \quad \ldots\ldots(9)$$

In this case FeO is formed on the slag side of the interface and must diffuse across into the metal according to reaction (8) before influencing reaction (6). Reaction (9) is very slow, so that reaction (7) may well control the oxygen content of the metal which in turn controls the sulphur equilibrium. It is postulated that below a certain FeO content of the slag the rate of transfer of FeO to the metal is such that the oxygen content is entirely controlled by the carbon–oxygen reaction. The slower the rate of formation of FeO by silica reduction the more quickly will this dynamic equilibrium be established and the lower will be the FeO content of the slag when the steady state has been reached. The rate of silica reduction can be expected to decrease as the silicon content of the metal increases, which is in agreement with the observed difference between the results of the present investigation and those of Hatch and Chipman. It also accords with the observations of Grant, Troili, and Chipman,[3] who found that the sulphur equilibrium was reached more rapidly with high-silicon iron.

According to the suggested mechanism it should be possible to speed up the approach to equilibrium and also to shift the equilibrium distribution by adding a strong deoxidant to the metal. In some experiments with samples of blast-furnace slag and metal it was shown that the addition of about 0·1% aluminium to the iron halved the time required to reach sulphur equilibrium. However, the experiment cannot be regarded as conclusive because the (FeO) content of the slag might also have been reduced, but analysis for FeO is too uncertain to decide whether or not this was so.

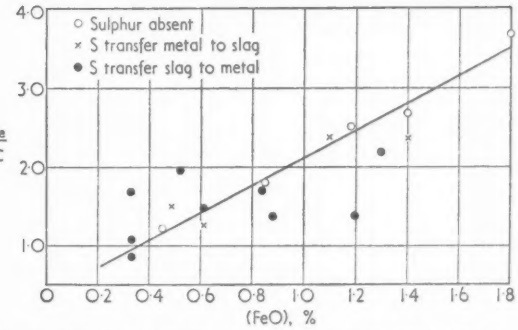


Fig. 3—Oxygen activity of metal as measured by the ratio a_{Fe}/a_C and FeO content of slag

EFFECT OF (FeO) ON SULPHUR DISTRIBUTION EQUILIBRIUM

The results of the experiments on the effect of FeO on the sulphur distribution are given in Table II. In these experiments the equilibrium was approached from either side, *i.e.*, sulphur transferring from slag to metal and from metal to slag. Preliminary examination showed that the decrease in (S)/[a_S] with increasing FeO was less than would be expected from the expression

$$\frac{(S)}{[a_S]} \cdot FeO = \text{constant}.$$

One probable reason was that the activity coefficient of FeO was not constant even over the small

Table II

RESULTS OF EXPERIMENTS IN ALUMINA CRUCIBLES AT 1500° C.

Expt. No.	Time, hr.	Sulphur Added to	Slag Analysis, wt.-%			FeO, %	S, %	Metal Analysis, wt.-%			f_S	$\frac{(S)}{[a_S]}$
			CaO	SiO_2	Al_2O_3			Si	C	S		
22	6	Metal	28·6	26·1	44·2	0·21	1·02	1·91	1·64	0·700	2·1	0·710
38	3	Slag	29·3	29·1	41·6	0·24	0·62	0·28	3·28	0·161	2·7	1·43
36	3½	Slag	31·6	27·3	40·0	0·25	0·97	0·18	2·61	0·268	2·1	1·72
18	4	Metal	30·3	28·2	40·4	0·31	0·46	2·48	2·02	1·29	2·6	0·135
25	4	Slag	29·9	26·8	42·7	0·33	0·45	0·22	3·96	0·198	3·4	0·661
27	5	Slag	28·3	25·7	44·5	0·33	0·82	0·26	3·68	0·241	3·1	1·11
34	3	Slag	31·4	27·8	40·2	0·33	0·54	0·21	3·48	0·296	2·8	0·641
16	6	Metal	29·6	25·4	44·9	0·48	0·41	0·12	1·98	1·13	1·6	0·224
15	4	Metal	30·0	24·1	44·8	0·49	0·42	0·01	2·44	1·08	1·8	0·212
14	3	Metal	31·3	23·3	43·6	0·50	0·38	0·11	2·42	1·03	1·9	0·199
31	4	Slag	28·1	31·5	39·3	0·52	0·28	0·13	3·15	0·263	2·4	0·443
35	3½	Metal	29·5	26·0	44·6	0·55	0·48	0·06	2·58	0·665	2·0	0·371
48	3	Metal	28·7	22·9	47·5	0·61	0·69	0·23	2·20	1·32	1·75	0·299
33	3½	Slag	32·0	25·1	41·5	0·61	0·48	0·10	3·56	0·324	2·8	0·534
49	6	Slag	29·5	26·2	44·3	0·84	0·64	0·59	3·08	0·470	2·6	0·516
32	4	Slag	31·4	24·9	42·1	0·88	0·64	0·17	3·61	0·301	2·9	0·733
37	3	Metal	28·1	24·3	46·3	0·95	0·25	0·04	1·60	0·840	1·4	0·207
45	3½	Metal	26·5	22·2	49·5	1·10	0·27	0·06	1·61	1·47	1·4	0·132
52	10	Slag	27·2	26·5	45·6	1·20	0·56	0·18	3·64	0·321	2·9	0·606
30	4	Slag	29·6	31·0	37·7	1·29	1·21	0·10	2·76	0·622	2·1	0·930
46	3½	Metal	29·0	25·9	42·7	1·40	0·14	0·12	1·30	1·75	1·3	0·063
51	6	Metal	28·2	25·4	45·3	1·50	0·16	0·02	0·30	4·18	0·88	0·044

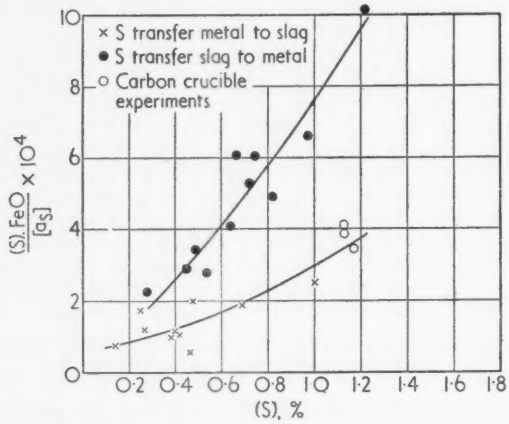


Fig. 4—Variation of sulphur reaction 'constant' with sulphur content of slag

range of concentration. For these experiments in which equilibrium in the reaction

$$FeO + \underline{C} = Fe + CO$$

was reached, the activity of FeO could be calculated. The free-energy change for this reaction is $-27{,}475$ cal. at 1500° C., whence $a_{FeO} = 4{\cdot}07 \times 10^{-4}$. a_{Fe}/a_C but because of the sulphur in solution in the iron there are difficulties in estimating a_{Fe} and a_C. They can, however, be estimated in the simple Fe–C alloy and experiments were therefore made to determine the C–FeO equilibrium with sulphur absent. The results are shown as a_{Fe}/a_C *vs.* (FeO) in Fig. 3 and confirm that f_{FeO} does vary even over this restricted range.

From this curve values of a_{FeO} were calculated for the results in Table II and then values for $(S)/[a_S] \cdot a_{FeO}$. These latter are shown in Fig. 4, where it is evident that they fall into two groups depending upon whether equilibrium was approached by sulphur transferring from metal to slag or *vice versa*. The values for metal-to-slag transfer lie on a smooth curve together with results of carbon-crucible experiments using values of a_{Fe}/a_C as a measure of the true value of a_{FeO}. Since it has been shown that these are equilibrium values it is *prima facie* evidence that equilibrium was attained in the FeO experiments in which sulphur transferred from metal to slag. Equally so, equilibrium was not attained in the other group of experiments. This is rather surprising since the experimental time was varied from 3 to 10 hr. and the results agree quite well among themselves.

This raises the problem of the reliability of the reported FeO values. Because there was little or no reduction of silica in these experiments and because the sulphur content of the slags was in general below that which appears to interfere seriously with magnetic separation of iron particles, the FeO values are considered to be fairly accurate. This is an opinion which is substantiated by the good agreement between the first group and the carbon-crucible experiments. There is no reason to suppose that the FeO values in the second group are any less reliable than the first.

A further check on the experiments can be obtained by calculating the values of a_{Fe}/a_C from the metal analyses given in Table II. As already pointed out, this is more difficult than in the case of the simple Fe–C binary because of the presence of sulphur. Values for the activity coefficient of carbon in the Fe–C–S system have been given by Kitchener, Bockris, and Spratt.[11] Estimation of the activity of iron is more uncertain but it appeared that the empirical method of Sherman and Chipman[6] could be extended to the estimation of the activity of the solvent.

The activity coefficient (f_C^S) of carbon with respect to sulphur in the Fe–C–S system is first required. From the known curve (Fig. 5*a*) for the activity coefficient f_C^{Fe} of carbon in iron solution the amount of carbon which would give the same activity coefficient (Fig. 5*c*) as a given sulphur concentration is obtained. This carbon equivalent of sulphur added to the actual carbon content gives the total equivalent carbon. The combined effect of carbon and sulphur on the activity coefficient of carbon can be represented by this total equivalent carbon in the binary and the value can be read from Fig. 5*a*. The activity of carbon is then the product of this coefficient and the carbon concentration. But the combined effect

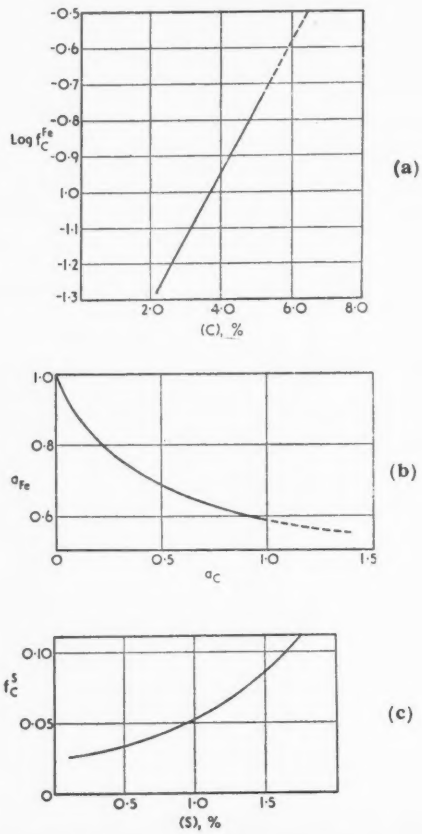


Fig. 5—Curves of activity coefficients

of carbon and sulphur on the activity of iron is represented by the total equivalent carbon activity, *i.e.*, the product of the total equivalent carbon and the activity coefficient. This when substituted in the a_{Fe}/a_C curve (Fig. 5*b*) gives a value for iron activity. Figure 5*b* is that calculated by Chipman[12] using the Gibbs–Duhem equation.

Values of f_C^S can be estimated from the data of Kitchener, Bockris, and Spratt by reversing the above procedure. It is necessary to extrapolate the log f_C^{Fe} *vs.* C curve (Fig. 5*a*), because as the carbon saturation value decreases with increasing sulphur content so must f_C^{Fe} increase above the limiting value of the binary solution. The derived curve for f_C^S *vs.* S is given in Fig. 5*c*. It agrees very well with that which Kitchener, Bockris, and Spratt calculated from the relationship $f_C = f_C^{Fe} \cdot f_C^S$ if account is taken of the fact that in the one case the standard state is pure carbon and in the other infinite dilution of carbon in iron.

The curve of a_{Fe}/a_C must also be extrapolated for high-sulphur, carbon-saturated iron, although this extrapolation was only required for two of the present experimental results. This extension of an empirical method of combining activities is rather speculative and in the absence of independent measurements of iron activity confirmation is difficult. At present it can only be said that a_{Fe} values so calculated are consistent with the experimental results both of the present investigation and of a similar one involving the Fe–C–Si system.[13] In both cases, too, the effect of the second solute (S or Si) is small compared with carbon in the range studied.

Values of a_{Fe}/a_C for those experiments in Table II in which it was certain that the iron was carbon-saturated initially are included in Fig. 3. The results for the experiments in which equilibrium was approached from the metal side lie close to the line of the sulphur-free experiments, indicating that the C–FeO equilibrium had been reached. For the other group in which oxygen and sulphur transferred from slag to metal there is considerable scatter. Evidently for this group the approach to the C–FeO equilibrium is also unsatisfactory.

On the basis of the proposed reaction mechanism there is a good reason why the approach to equilibrium should be slower when sulphur transfer is from slag to metal than from metal to slag. In the former case oxygen ions (plus iron ions) first diffuse into the metal where they take part in both carbon and sulphur reactions, *i.e.*, the carbon reaction retards the approach to sulphur equilibrium. In the latter case the oxygen content of the metal resulting from the sulphur reaction is reduced both by the carbon reaction and by diffusion across the interface, *i.e.*, the carbon reaction accelerates the approach to equilibrium.

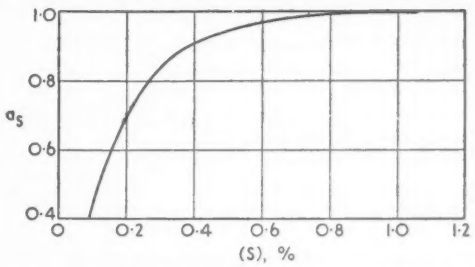


Fig. 6—Sulphur activity and percentage in slag

There is also a thermodynamic reason why the approach to equilibrium should be slower when the equilibrium is approached from the high-sulphur slag side. Carbon and sulphur in iron solution raise the activity of each other. When sulphur transfers from metal to slag both carbon and sulphur concentrations decrease, the activity coefficients decrease, and the approach to equilibrium is accelerated. But when the sulphur and FeO concentrations in the slag are high initially, the sulphur concentration in the metal increases as reaction proceeds; carbon, however, decreases. The increase in sulphur content causes the activity coefficient of carbon to increase and thus retards the approach to the C–FeO equilibrium. Similarly the decrease in carbon content lowers the activity coefficient of sulphur and thus retards the build-up of the activity to the equilibrium value. This may not be a complete explanation for the extreme sluggishness of the reaction when approached from the high-sulphur slag side. It is, however, of interest to observe that the case of the simultaneous reactions of carbon and silicon in iron solution with oxidizing slags is also complicated by the mutual interaction of each solute on the activity coefficient of the other.

The significance of the increase in the product $(S)/[a_S] \cdot a_{FeO}$ shown in Fig. 4 is that the activity coefficient of sulphur in slag varies with the sulphur content. If relative activities are calculated it is found that a constant value is approached at a sulphur concentration of about 1·0%, which means that sulphur saturation is reached. Putting this as unit activity a curve showing the variation of (a_S) with %S is obtained (Fig. 6). Confirmation that sulphur saturation for this slag is about 1·0% was obtained by bringing slag and metal to equilibrium in a carbon crucible with increasing amounts of sulphur in the slag. As shown in Table III the metal sulphur remained constant for slag sulphur greater than

Table III

SATURATION EXPERIMENTS

Expt. No.	(CaO)	(SiO_2)	(Al_2O_3)	(S)	[Si]	[C]	[S]	f_S	$[a_S]$
63	30·2	26·5	41·7	1·03	0·52	4·84	0·122	5·7	0·695
64	29·2	26·7	42·7	1·56	0·61	4·80	0·127	5·7	0·723
65	28·5	27·3	41·8	2·14	0·65	4·73	0·128	5·6	0·716

Table IV

ACTIVITY OF CaO IN $CaO–Al_2O_3–SiO_2$ SLAGS

Slag Composition (CaS-free), %				Excess Base, moles/100 g. slag	a_{CaO}
MgO	CaO	Al_2O_3	SiO_2		
...	29	45	26	−0·37	0·003
4·5	39	19	37·5	−0·11	0·006
6·5	41·5	15	37	+0·05	0·020

about 1·0%, *i.e.*, the slag must be saturated with sulphur, presumably as CaS.

This is an unusually low value of CaS solubility. A similar experiment with a more normal blast-furnace slag gave a solubility limit of about 4% of sulphur. This agrees with Filer and Darken's value of 3·5–4·5% for a rather more basic slag. Values for the activity of lime in these three slags have been calculated and in view of the paucity of published data are shown in Table IV. The activities were calculated through the free-energy change for the reaction

$$[S] + CaO + C = CaS + CO$$

for which Rosenqvist gives $-\Delta G^\circ = 27{,}050 - 27{\cdot}55\,T$ cal. Filer and Darken did not determine the sulphur in iron in equilibrium with their slag but an estimated value can be obtained from the results of Hatch and Chipman for slags containing 5% of sulphur and therefore presumably saturated with CaS at the composition of Filer and Darken's slag. The slag compositions are quoted in Table IV converted to a CaS-free basis.

DISCUSSION

The almost negligible temperature coefficient for the desulphurization reaction at the oxygen potential of carbon is rather surprising. According to the quoted thermodynamic data the ratio $(a_{CaS})/[a_S](a_{CaO})$ should increase about 60% from 1450° to 1550° C. The experimental evidence is quite definite that $(\%CaS)/[a_S](\%CaO)$ is virtually independent of temperature in this range. Since the thermodynamic data seem unlikely to be seriously at fault, this would indicate that the activity of CaS increases and/or that of CaO decreases with increasing temperature. Any change in a_{CaS} with rising temperature is almost certainly downwards because the solubility of CaS can be expected to increase. Apparently, therefore, a_{CaO} must decrease with rising temperature. This implies that the dissociation of lime aluminosilicates has less effect on the activity than increase in solubility with temperature. However, more complete data both on the activity of CaS and CaO are necessary to clarify this point.

The effect of FeO on the reaction appears to be quite straightforward although there is a marked change in the activity coefficient of FeO in the slag used in this investigation even in relatively dilute solution. Whilst it is true that the slag did not have a typical blast-furnace slag composition a similar effect may be expected for the more normal type. In view of the significance of the FeO content or oxygen potential of these slags both for the sulphur and silicon reactions, the activity coefficient of FeO in dilute solution is of great importance. The extreme sluggishness of the transfer of sulphur from slag to metal as compared with metal to slag could play a significant role in the blast-furnace. The cross-sectional area of a modern blast-furnace is extremely large and the variations in oxygen potential which obtain over this area tend to be overlooked.

The equilibrium desulphurization ratios may be compared with those obtained in practice. Data from a fairly wide range of basic iron practice have been collected and are given in Table V. In one case the carbon content of the iron was not reported and a value was assumed. The ratio $(\%S)/[a_S]$ was calculated for direct comparison with the curve of Fig. 2. It may be noted, however, that $f_S = 4{\cdot}5$ for iron of composition:

Si,%	P,%	Mn,%	C,%
0·8	1·0	1·0	4·0

Since f_S varies little for the normal range of basic iron composition the values shown in Fig. 2 multiplied by 4·5 represent a good approximation to the equilibrium values of (%S)/[%S] for basic iron.

It has been confirmed that the desulphurization ratios quoted in Table V are about one-half to one-third of those corresponding to equilibrium at the oxygen potential of C–CO. There are good grounds, for example the regular formation of kish, to suppose that blast-furnace iron usually is saturated with carbon, *i.e.*, that it has the oxygen potential of solid carbon. As already pointed out, whilst the high values of FeO reported for blast-furnace slag suggest

Table V

DESULPHURIZATION RATIOS FROM PRACTICE

Plant	Slag Analysis, wt.-%				S, %	Excess Base, moles/100 g. slag	Metal Analysis, wt.-%					f_S	% S/[% S]	
	CaO	MgO	SiO_2	Al_2O_3			Si	S	P	Mn	C		Equilibrium	Actual
1	49·5	2·7	34·1	13·8	1·48	0·226	0·7	0·027	0·4	1·4	4·2	4·5	140	55
2	46·3	3·7	31·7	18·3	1·49	0·174	0·9	0·070	1·4	0·7	3·9	4·2	105	21
3	45·7	3·3	36·1	14·9	1·59	0·126	0·7	0·036	low	2·4	4·3	4·4	84	44
4	40·7	6·0	35·5	17·8	1·62	0·061	0·9	0·072	0·7	1·0	4·05	4·6	57	22
5	41·8	4·2	34·2	19·8	1·61	0·060	1·1	0·075	1·4	1·2	3·5	4·1	51	22
6	39·6	6·3	35·3	19·8	1·34	0·040	0·8	0·078	1·0	1·1	3·9	4·4	40	17
7	41·1	3·5	36·0	19·4	1·57	0·000	0·6	0·083	1·6	1·1	3·8	4·6	27	19
8	35·7	4·7	33·7	25·9	1·8	−0·099	0·6	0·13	2·0	1·4	3·8	4·7	38	14

that the oxygen potential of the slag is considerably above that of the iron, little reliance can be placed on the 'FeO' values. Attempts have been made from time to time to use the MnO/Mn ratio for which the analysis is straightforward and reliable. Unfortunately the temperature coefficient of the reaction

$$MnO + C \rightleftharpoons Mn + CO$$

is much greater than for FeO reduction so that it is more essential to have temperature measurements. There is in addition the usual difficulty with regard to activities in slag and metal solution. Values of the MnO/Mn ratios are available for three of the examples quoted in Table V for which slag and metal temperatures are also shown. Estimates of the oxygen potential have been made for these cases. Grant, Kalling, and Chipman[2] give values for the manganese distribution at or near equilibrium and in contact with carbon at 1525° C. For the two slags nearest the composition range in question the values are fairly close to a mean of 15/85 for slag/metal which corresponds to an (MnO)/Mn ratio of about 0·22. From thermodynamic data given by Richardson and Jeffes,[14] equilibria for the reaction can be calculated: $(a_{MnO})/(a_{Mn})$ varies from 1·0 at 1427° C. to 0·34 at 1527° C. The value for %MnO/%Mn at any given temperature is obtained by simple proportion from the quoted experimental value for 1525° C. and the respective theoretical values. The assumption made here is that the effect of temperature and composition on the activity coefficients of MnO (Mn) in slag (metal) solution is small and may be ignored. The temperatures quoted are mean values, but it had been found in each case that the temperature of the metal towards the end of the cast was approximately 20° C. higher and equal to that of the roughing slag. For the purpose of the calculation, therefore, the mean metal temperature plus 20° C. was taken as the reaction temperature.

These calculated equilibrium values together with the actual values are given in Table VI. An idea of the possible error involved in the calculation may be obtained from figures given by Filer and Darken.[7] For a rather more basic slag their results for equilibrium at 1400° and 1500° C. give (%MnO)/[%Mn] = 0·44 and 0·19. This represents a smaller temperature coefficient than that calculated for $(a_{MnO})/[a_{Mn}]$. The estimated equilibrium values therefore probably err on the high and the oxygen potentials on the low side. Table VI shows that the desulphurization ratio in practice is at least as good as that corresponding to the oxygen potential of the slag. This implies that the retarding factor in the approach to the equilibrium sulphur distribution is not the sulphur partition reaction but reduction of FeO (MnO) in the slag. In this case, factors controlling the reduction of the slag are of great importance for desulphurization.

Estimation of the oxygen potential of slag remains a problem. Because of the pronounced temperature coefficient, the (MnO)/[Mn] ratio is not satisfactory and for the same reason neither is the silicon content of the metal advocated by Oelsen.[15] Estimation of the activity of FeO appears to be the best method if the problem of separating the included iron shot from the slag could be solved.

Table VI

COMPARISON OF DESULPHURIZATION RATIOS AND OXYGEN POTENTIALS FROM PRACTICE

Plant	(% MnO)/[% Mn]		Mean Metal Temp., ° C.	Oxygen Potential Relative to that of Carbon	Equilibrium (S)/[S] / Actual (S)/[S]
	Equilibrium	Actual			
4	0·6	1·3	1415	2·2	2·6
5	0·65	1·1	1405	1·7	2·3
6	0·45	1·2	1440	2·5	2·3

It has been shown that blast-furnace slag has considerable desulphurizing power with respect to the metal as tapped, which raises the question of continuing desulphurization outside the furnace. The problem appears to be chiefly one of reducing the oxygen potential of slag and/or metal. The possibility of using a deoxidant might be worth considering. Since the total amount of sulphur left in the metal is small, desulphurization could be continued with only a fraction of the total slag bulk without raising the sulphur content of the slag greatly.

Acknowledgments

The authors wish to express their appreciation of the interest taken in this work by Professor Hay; one of them (J.J.S.) also thanks the British Coke Research Association for financial support.

References

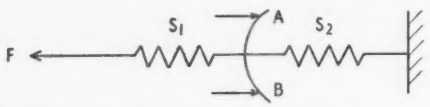
1. G. G. Hatch and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1949, vol. 185, pp. 274–284; *J. Met.*, 1949, vol. 1, Apr.
2. N. J. Grant, U. Kalling, and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, pp. 666–671; *J. Met.*, 1951, vol. 3, Aug.
3. N. J. Grant, O. Troili, and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, pp. 672–673; *J. Met.*, 1951, vol. 3, Aug.
4. J. P. Morris and A. J. Williams, jun.: *Trans. Amer. Soc. Metals*, 1949, vol. 41, pp. 1425–1439.
5. J. P. Morris and R. C. Buehl: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 317–322; *J. Met.*, 1950, vol. 2, Feb.
6. C. W. Sherman and J. Chipman: *Trans. Amer. Inst. Min. Met. Eng.*, 1952, vol. 194, pp. 597–602; *J. Met.*, 1952, vol. 4, June.
7. E. W. Filer and L. S. Darken: *Trans. Amer. Inst. Min. Met. Eng.*, 1952, vol. 194, pp. 253–257; *J. Met.*, 1952, vol. 4, Mar.
8. T. Rosenqvist: *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, pp. 535–540; *J. Met.*, 1951, vol. 3, July.
9. C. Wagner: "Diffusion in Solids, Liquids, and Gases," p. 381: 1952, New York, Academic Press Inc.
10. G. Derge, W. O. Philbrook, and K. M. Goldman: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 1111–1119; *J. Met.*, 1950, vol. 2, Sept.
11. J. A. Kitchener, J. O'M. Bockris, and D. A. Spratt: *Trans. Faraday Soc.*, 1952, vol. 48, pp. 608–617.
12. J. Chipman: *Disc. Faraday Soc.*, 1948, No. 4, pp. 23–49.
13. J. Taylor and G. Arthur: Unpublished results.
14. F. D. Richardson and J. H. E. Jeffes: *J. Iron Steel Inst.*, 1948, vol. 160, pp. 261–270.
15. W. Oelsen: *Stahl u. Eisen*, 1948, vol. 68, pp. 175–186.

LETTER TO THE EDITOR

Grain-Boundary Properties Effecting Cleavage Fracture

A theory to account for the grain-size effect on the measured values of brittle strength of polycrystalline metals has been advanced by Petch.[1] In this theory the grain boundaries are regarded as the barriers against which dislocations pile up, thus concentrating the applied stress in their neighbourhood. Petch concludes that "since a property of the grain-boundary region is involved, subtle effects of composition are possible, owing to the segregation of solute atoms to this special region and to the effect of other solute atoms on this segregation." He also remarks that his conclusions are valid only for those cases where precipitates, which might act as stress-raisers, are absent.

We intend to assign a hypothetical property to the grain boundary which might have some relevance to Petch's statement. This property, which we call 'stiffness,' can be described conveniently by a mechanical analogy. In the diagram, AB is an elastic diaphragm



supported at its rim; to it are attached springs S_1 and S_2 at its centre on either side. When a force F is applied to S_1, the fraction of this force supported by S_2 depends inversely on the stiffness of AB. The springs S_1 and S_2 represent the elastic properties of two adjacent crystals in a polycrystalline aggregate and AB corresponds to a complicated dislocation array constituting a segment of the grain boundary. Discontinuity of elastic stress and strain can then occur across this assumed elastic boundary in proportion to its stiffness. The stresses and strains referred to are those due to the pile-up and are highly localized. This concept has a parallel in the idea of grain-boundary pressure put forward by McLean[2] to explain the speed-dependence of the migration, induced by stress, of grain boundaries at elevated temperatures; such migration has its analogy in creep of the diaphragm in the mechanical model. It is clear, therefore, that in Petch's theory of the genesis of cleavage the piled-up array will be more intense in proportion to the stiffness of the boundary; yield in the second grain to relieve the situation (by the activation of a Frank–Reade source there) will be delayed to a higher level of applied stress and conditions for cleavage will thus be favoured. In effect, the notch-bar transition temperature will be increased.

To account for variability in this property of stiffness, the idea of locking by interstitial atoms is invoked. Cottrell and Bilby[3] have shown that large forces are required for the first small displacement of a single dislocation from a condensed atmosphere of interstitial atoms; a similar state of affairs may apply to the lattice irregularity at a grain boundary, the resultant stiffening being related to the degree of saturation by interstitial atoms at the boundary. The disappearance of the yield point in ferrite containing carbon or nitrogen at some moderately elevated temperature (about 400° C.) suggests that dislocations are unlocked from their atmospheres, and presumably the interstitial atoms may disperse to an extent dependent on the temperature. This condition can be 'frozen in' by quenching, and thereafter the yield point returns, increasing in intensity to a steady value as the ageing time increases. It may be supposed that a similar process goes on at the grain boundary and that the degree of grain-boundary saturation (and therefore of stiffening) can be controlled by subcritical heat-treatments.

Unambiguous evidence for the reality of this hypothetical property cannot be obtained from published data because of the intrusion of other factors such as grain size, precipitate formation, chemical composition, and continuous grain-boundary films,[7] these being among the most important; specially designed experiments would be required. Quench-ageing experiments, where grain-boundary atmospheres can be dispersed and re-formed by ageing, provide the field where such evidence may be sought. Typical experiments are those of Low,[4] who measured the notch-impact properties of a semi-killed steel containing 0·17% C and 0·75% Mn. The lowest transition temperature was given by material in the quenched condition (from 690° C.), the transition temperature being found to increase progressively with ageing time. Similarly, specimens which had been quenched, air-cooled, and furnace-cooled, respectively, were found to have transition temperatures which increased in that order. These facts could be reconciled to the present view but, as previously noted, not without ambiguity. The same is true of the established observation that nitrogen-scavenging by aluminium favours lower transition temperatures.[5] On the other hand, evidence that interstitial atmospheres can disperse and re-form at grain boundaries is more positive. This can be seen by considering another property of the grain boundary, namely its cohesive strength. Low and Feustel[6] have suggested that interstitial atoms can increase the grain-boundary cohesive strength by increasing the binding energy between widely separated iron atoms. This seems to be borne out by Allen *et al.*[7] on high-purity iron–carbon alloys, which were tension-tested at −196° C. in the furnace-cooled, air-cooled, and water-quenched conditions (from 950° C.). For the last heat-treatment, where boundary saturation is unlikely, partial intergranular fracture occurred at the expense of tensile strength with carbon contents up to 0·053%. Although this effect was absent in furnace-cooled specimens, it did recur when the same furnace-cooled material was reheated and quenched from 700° C. Similarly, for material previously quenched from 950° C., subsequent slow cooling from 700° C. removed the tendency to intergranular fracture. These facts could be interpreted in terms of the dispersal and re-forming of grain-boundary atmospheres. It was also found that intergranular weakness was nullified by the addition of manganese, thus making the latter results consistent with those of Low.[4]

J. Short
A. Muscott

Admiralty Materials Laboratory,
R.N.S.S.,
Holton Heath,
Poole,
Dorset

7th May, 1954

1. N. J. Petch: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 25–28.
2. D. McLean: *Nature*, 1953, vol. 172, pp. 300–301.
3. A. H. Cottrell and B. A. Bilby: *Proc. Phys. Soc.*, 1949, vol. 62, ser. A, pp. 49–62.
4. J. R. Low, jun.: *Welding J.*, 1952, vol. 31, pp. 253s–256s.
5. G. W. Geil, N. L. Carwile, and T. C. Digges: *J. Res. Nat. Bur. Stand.*, 1952, vol. 48, pp. 399–406.
6. J. R. Low, jun., and R. G. Feustel: *Acta Met.*, 1953, vol. 1, pp. 185–192.
7. N. P. Allen *et al.*: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 109–120.

DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Annual General Meeting 1954

THE EIGHTY-FIFTH ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held in London on Wednesday and Thursday, 26th and 27th May, 1954, at the Royal Institution, Albemarle Street, W.1, and at the offices of the Institute, 4 Grosvenor Gardens, S.W.1.

The reports of the discussions at the Meeting were published in the October issue of the *Journal* (pp. 147–164). The following authors' replies were held over owing to lack of space.

DISCUSSION ON STRUCTURE OF CAST IRONS

The discussion was based on a group of papers published in the *Journal* for April, 1954; the titles are given in the October issue, p. 153.

AUTHORS' REPLIES

Professor **A. Hultgren** and Mr. **G. Östberg** wrote: In reply to Dr. Riley's question, we believe that the hydrogen (and/or sulphur) dissolved in the matrix, austenite or cementite, affects the mechanism of growth of graphite so as to promote spherulite formation. For reasons given in our paper, we have ventured to suggest that the relation between the rates of growth in the *a*-axes and the *c*-axis directions is modified, the former rate being retarded. We suppose Dr. Riley would consider such an action to be direct.

Mr. Turner's kind remarks on the quality of our micrographs are appreciated. Except for one case of medium magnification (× 400), only high magnifications were employed (× 1000, 1200, 1500, and 2000), the selection being governed by the idea of using the highest useful magnification compatible with the size of the particular feature under consideration. We are not in favour of too rigid adherence to a few standard magnifications. The objectives mostly used were: fluorite × 140 oil immersion, n.a. = 1·30, and achromate × 85 oil immersion, n.a. = 0·95. With polarized light (+ and −+−) the latter was used exclusively.

Dr. Owen, in a study of pure Fe–C–Si alloys, found that nucleation of graphite during annealing invariably occurred at a cementite/austenite interface. We look forward with interest to a forthcoming paper providing the experimental evidence for that conclusion. In the irons of high S : Mn ratio and commercial purity which we studied, interfaces of several kinds appeared to serve as nucleation sites for graphite, the dominant one being sulphide/austenite. We should perhaps emphasize again that, nevertheless, by far the greater part of the sulphide/austenite interface area available remained free from graphite after annealing.

Mr. Lindblom believes that the growth of spherulitic graphite around sulphide is due to an inherent tendency for curved growth. Presumably, this tendency would increase with sulphur and hydrogen. That view, in our opinion, would not account for the observation that, during such a gradual change in composition, the type of graphite formed is altered, from flakes, often curved (Figs. 20, 34, and 35 of our paper), to equiaxed particles not having a curved shape (Fig. 36) and, finally, to spherulites, with pronounced curvature coinciding with an interface. The latter change seems to call for some kind of guiding influence from the interface gaining in relative power over certain other growth tendencies which are restricted. Typical spherulites containing an austenite core were very rare (Figs. 51*a* and *b*), whereas sulphide cores were common in such spherulites. We conclude, therefore, that, in the irons studied, a suitable core/particle interface was probably one of the essential conditions for the formation of a true spherulite. For the special type of spherulite shown in Fig. 63*b* this condition would not necessarily apply.

We are pleased to have Mr. Morrogh's confirmation of our observation that hydrogen promotes the formation of spherulitic graphite. For evaluating the magnitude of that effect we wish to refer to our Figs. 4–6.

Mr. Morrogh suggests that film-like formation of graphite at interfaces may be connected with the presence of liquid in the specimens being annealed and calls our attention to the phosphorus contents of our irons which were 0·04–0·08%. Although we hardly believe liquid to have been present at 900° C., at which temperature spherulites were formed (Fig. 47), and although we should expect liquid high in phosphorus to have been detected in the microstructures of the quenched specimens as bands or areas containing phosphide we are grateful for the suggestion and have carried out the following investigation.

A 2-kg. melt of white iron was prepared in the graphite crucible of a H.F. furnace and cast in green-sand moulds into 10-mm. dia. rods. The iron had the following percentage composition: C, 2·78; Si, 1·39; Mn, 0·07; P, 0·012; S, 0·26; S : Mn = 3·7. Discs 5 mm. thick were annealed at 1000° C., packed in the carburizer referred to in our paper, and quenched in brine.

After 2½ hr. a considerable number of graphite particles had formed, most of them being small spherulites while a few compact nests were also present. In the spherulites, sulphide cores were rather common, the sulphide being iron sulphide with occasionally some manganese sulphide.

Figure *A* shows two spherulites with sulphide cores. In one of them, the growing graphite has completed its encirclement of the sulphide core, while in the other, film-like growth along the interface is in evidence.

Since liquid metal could hardly have been present in a white iron of as low a phosphorus content as 0·012% at 1000° C. we conclude that Mr. Morrogh's suggestion as to the presence of liquid being essential for film-like growth of graphite has not been corroborated by our experiment.

Professor **A. Hultgren,** Mr. **Y. Lindblom,** and Professor **E. Rudberg** wrote: We are pleased to note Mr. Williams's statement that, in his opinion, we have definitely established the sequence in the formation of our grey and white structures; in particular that he agrees that the rosette type of graphite obtained in our irons *A* and *B* must have formed directly from the liquid. Since the central part of each rosette in iron *B* contains fine undercooled graphite (*cf.* Fig. 16 of Morrogh and Williams[1]), the evidence for formation of undercooled graphite directly from the liquid melt, which we have presented, is thus accepted as conclusive. On the other hand it is maintained that undercooled graphite also forms in cast irons by a kind of malleablizing reaction, through a process depending on the simultaneous disappearance of ledeburite first precipitated.[1] It would thus seem that according to Mr. Williams's present view there are two kinds of undercooled graphite, differing from each other at least through the process by which they are generated. It would be interesting to know if Mr. Williams thinks that the difference also is manifest in structural appearance and, if so, how he proposes to distinguish one kind from the other—in particular, whether the presence or absence of rosette arrangement constitutes an important criterion.

Mr. Morrogh relates a case of rain-water gutters, $\frac{3}{16}$ in. thick, which are cast in a cast-iron mould. If left to cool in the mould the casting comes out white, but if stripped immediately upon solidification it exhibits a grey structure with undercooled graphite. It seems to us that these conditions of manufacture are too special for this case to furnish a representative example of sand castings showing undercooled graphite. Probably the silicon content is high and in consequence the malleablizing reaction, which should set in after stripping, would be expected to be very rapid. It would be quite interesting to examine the structure of such castings, preferably in a series with increasing time delay before stripping, whereby a range of stages between grey and white could perhaps be obtained.

Mr. **H. Morrogh** and Mr. **W. J. Williams** wrote: Various reasons have been put forward to explain our observations on the formation of undercooled graphite. We have no wish to be dogmatic and in fact, following the discussion, we feel that neither the direct nor the indirect formation of the undercooled form of graphite has definitely been proved. Obviously further experiment is required.

Contributors to the discussion have concentrated on the limited evidence presented in our paper and have ignored earlier published work, which lends weight to our views. Eash[2] first proposed that the fine form of graphite originated from the decomposition of iron carbide. This investigator quenched sand-cast bars after solidification and found white iron, whereas when the bars were allowed to cool slowly he obtained grey cast irons. How did Eash obtain this result if the fine form of graphite forms directly from the melt? Our work[1] in 1947 was to check Eash's observations and it gave similar results for a wide range of compositions and also for Ni–C alloys. We did point out that the carbide which might decompose to give undercooled graphite had an acicular pattern. Mr. Hillert and Mr. Hopkins have suggested alternative explanations for this structure in our quenched ingots. These explanations are plausible and need examination, but it should be remembered that we have demonstrated this acicular form of carbide in association with undercooled graphite under conditions of slow cooling. The areas of inverse chill found so frequently in the centres of sections having otherwise a completely undercooled graphite structure, have a characteristic acicular structure quite different from that of normal white iron. Furthermore, we showed that the carbide present in the austenitic iron Nicrosilal had an acicular appearance when the graphite was of the undercooled variety, and was of the massive normal type when the accompanying graphite was normal flake. The samples illustrated had been normally cooled in sand moulds. Clearly, the association of the acicular form of carbide with undercooled graphite is not a unique feature of quenched samples and cannot be lightly dismissed.

Shaw and Kondic[3] have produced evidence of the indirect formation of undercooled graphite from observations with a quite different experimental technique. Berman and Kondic[4] have demonstrated that undercooled graphite can form by decomposition of cementite at temperatures just below the freezing point. Furthermore, it is a practical experience in certain cast-iron die castings, that if the casting is allowed to cool in the mould it will be white, but if withdrawn immediately after solidification it will be grey with undercooled graphite. It is difficult to interpret this result except in terms of the indirect formation of undercooled graphite.

We have already pointed out that irons giving undercooled graphite structure frequently, if not always, show an inflection on the cooling curve prior to the eutectic arrest. This point has been overlooked by all except Dr. Berman, who questions its reality. Since also Professor Hultgren has asked to see our cooling curves in more detail a curve showing this inflection is reproduced in Fig. *C* for a 50-g. ingot having all its graphite in an undercooled form. This type of curve has been obtained on cooling curve ingots of a wide range of sizes but no inflection has been obtained on ingots of corresponding sizes which had flake graphite. In this connection the cooling curves for iron *C* given by Hultgren, Lindblom, and Rudberg need careful examination. In spite of their very careful experimental work, for which they deserve the highest praise, it is significant that there is an inflection beginning perhaps 10° C. or more above the eutectic arrest. However, the cooling curve for their white iron *D* shows no such inflection prior to the arrest and recalescence. Their irons *A* and *B* show some evidence of this inflection also, presumably because of the small amounts of undercooled graphite present in their structures.

Those who argue for the direct formation of undercooled graphite need at least to dismiss all the points listed above and not merely a few chosen observations from our paper. However, it is worth while to examine what experimental evidence can be brought in support

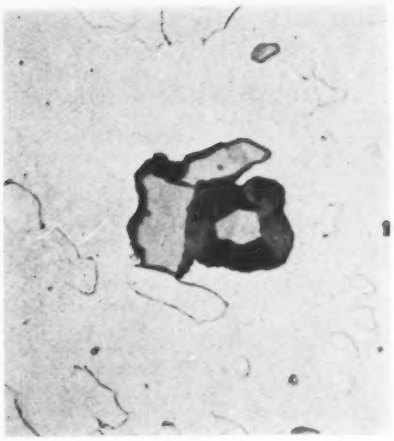


Fig. A—Iron with 0·012% P ; annealed at 1000° C. in carburizer, quenched : structure after 2½ hr. × 1500

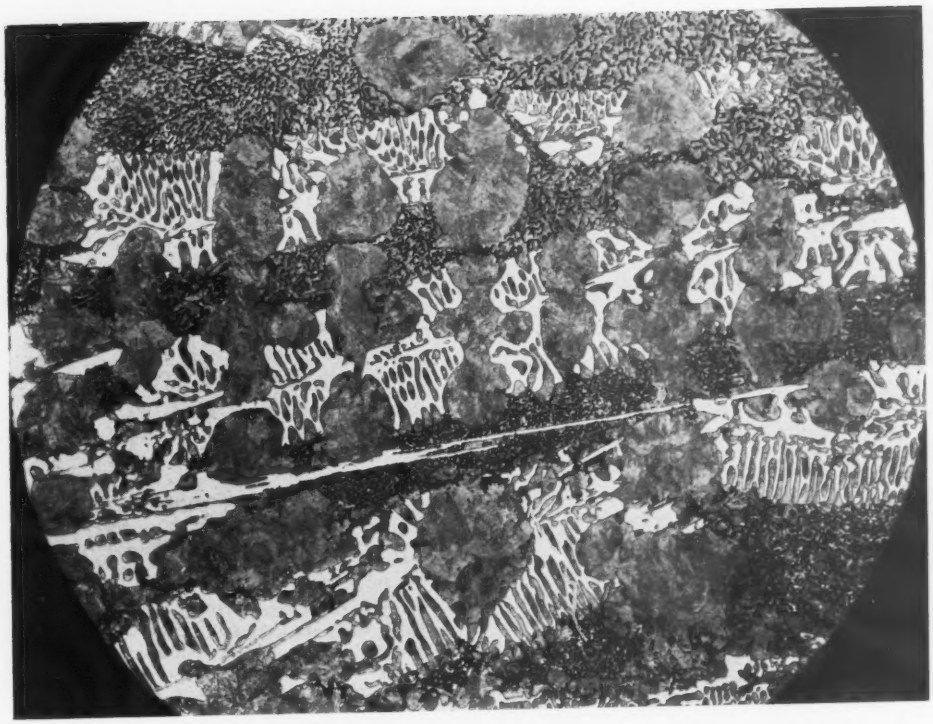


Fig. B—Mottled structure showing non-spherical outline of undercooled graphite areas. Etched in picral × 100

of the direct formation of undercooled graphite—apparently only the experiments of Hultgren, Lindblom, and Rudberg on their iron *C*. Now these investigators chose a material with a most unusual structure, of which undercooled graphite only constituted a part. In our work our cooling curves were obtained on alloys giving entirely undercooled graphite in the slowly cooled condition. The data presented by the Swedish investigators do not indicate that it was possible to detect the beginning of undercooled graphite formation nor to indicate its end. In fact by using an alloy with a composite structure they merely added to the experimental difficulties. We feel that all that may be deduced from these experiments is that if undercooled graphite forms indirectly, the cementite must decompose with great speed. The experimental work on irons *A* and *B* from the Swedish workers is also of little significance because they had mixed coarse and fine graphite.

Thus far in our opinion the weight of evidence is in favour of the indirect formation of undercooled graphite. However, the work of Hilliard and Owen[5] suggests the direct formation to be the most probable. These investigators made a careful study of the Fe–C–Si system and since they always found the undercooled form of graphite in their eutectic alloys, and since they also believed in the indirect formation of this graphite, they proposed a system in which the carbon-rich phase is iron carbide, Fe_3C. At first glance this apparently fits their observations and could be added to the material in support of the indirect formation of undercooled graphite. However, it was the intention of our paper to show that the assumptions by Hilliard and Owen were not justified, as the following will indicate.

When white irons of various silicon contents are examined it is found that up to about 2·7% Si the carbide phase consists of normal cementite, Fe_3C, but beyond 2·7% Si a silico-carbide begins to appear until at about 6·7–7·0% Si the whole of the eutectic carbide appears to be the silico-carbide. The structure of this carbide has been investigated by Owen[6] and we have attempted to indicate its composition.[7] Assuming that such a series with increasing silicon due to the graphitizing effect of silicon can only be produced by rapid cooling, Dr. Owen's contribution to the discussion seems to be in complete agreement with us. Beyond this, however, Dr. Owen refuses to see the implications of his assumptions.

Hilliard and Owen[5] quote Owen and Street[8] as the basis for their assumption that undercooled graphite in the Fe–C–Si system must arise from the decomposition of Fe_3C. However, Owen and Street made no attempt to examine carbide formed under conditions of slow cooling and retained by quenching. Furthermore, the only carbide examined was from an alloy having 2·44% Si, *i.e.*, a silicon content below the level at which the silico-carbide begins to appear. On the basis of this one alloy Hilliard and Owen have assumed that the undercooled graphite in all Fe–C–Si alloys up to at least 8% Si forms by the decomposition of Fe_3C.

If iron carbide, Fe_3C, is the carbon-rich phase from which the undercooled graphite forms in the Fe–C–Si system for alloys up to, say, 8% Si, then by the type of quenching experiments which we have conducted we should always find Fe_3C as the phase retained by quenching during or after the solidification process. If the indirect formation of graphite is correct such carbide or carbides would have been formed slowly prior to the quench and not during or after the quench. In fact we do not find Fe_3C in all such quenched alloys. At about 2·7% Si the silico-carbide begins to appear and at about 7·0% all the carbide is silico-carbide. Figure 5 of our paper[7] showed an alloy of such a composition

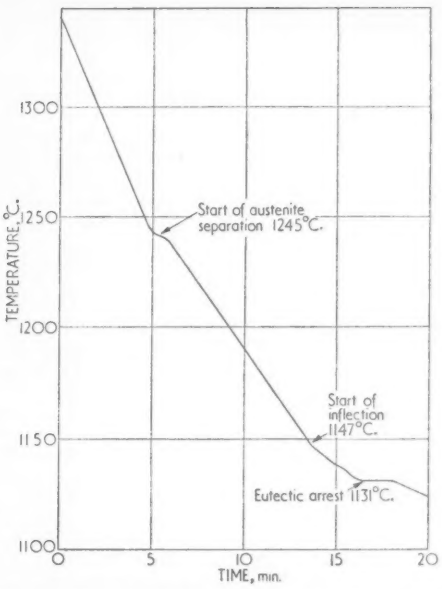


Fig. C—Cooling curves for 50-g. ingot of iron having all graphite in undercooled form and showing inflection prior to eutectic arrest

that Fe_3C and the silico-carbide were present. We previously claimed[1] to have demonstrated the indirect formation of undercooled graphite for an iron having 10% Si. Does Dr. Owen believe that this carbide was also Fe_3C? The carbide to which we refer in quenched alloys was formed prior to the quench under conditions of slow cooling if the indirect formation of undercooled graphite is correct, as Dr. Owen assumes.

If undercooled graphite forms indirectly from the melt Hilliard and Owen are incorrect because they do not show the occurrence of a silico-carbide in their diagram. In fact, it appears impossible to draw a diagram to indicate this. Thus we reach a point where there is a logical objection to the indirect formation of the fine form of graphite, since the development of the ternary equilibrium diagram presents no fundamental difficulties if it is assumed that the carbon-rich phase is graphite. This objection may only be sustained if it is valid to apply equilibrium-diagram principles to alloys showing marked undercooling. We know from experience that alloys having the fine form of graphite have undercooled and that higher freezing points are obtained if appropriate steps are taken to nucleate the melt.

This lengthy discussion is necessary since Dr. Owen has apparently for the second time[8] completely misunderstood our point of view and the consideration of the Fe–C–Si system is of great importance in relation to the mechanism of undercooled graphite formation. We submit that whichever way the formation of undercooled graphite is interpreted the propositions of Owen and Street are not justified.

The consideration of their work makes us uneasy about our own conclusions on the indirect formation of undercooled graphite. In addition, Berman and Kondic[4] have produced some evidence in support of our work and claim to have shown that the undercooled form of graphite can be produced rapidly by the heat-treatment of cementite just below the eutectic temperature. We have been completely unable to confirm this. We have found that cementite in pure Fe–C alloys does not decompose

rapidly at or near to the eutectic temperature and when it decomposes we have only obtained a flake form of graphite. These experiments have, in some cases, been carried out without cooling the sample below the isothermal heat-treatment temperature. When we have obtained undecomposed cementite in such isothermally treated specimens we have been certain that the samples contained carbide before the heat-treatment. On the other hand, Berman and Kondic's experiments are such that there is no guarantee that the samples which had undercooled graphite after reheating had any cementite before the heat-treatment.

Professor Hultgren says that the moment at which cementite forms as a second phase in a hypo-eutectic alloy is the moment when the eutectic reaction is initiated and suggests that this is not in accord with the terms we have used. For binary alloys we agree, but he should note that we talk of the 'eutectic arrest, as shown by a cooling curve.' We do not propose that the eutectic arrest corresponds to the beginning of the eutectic reaction. Professor Hultgren says that in his experience mottled structures appear to be characterized by a matrix of ledeburite in which spheroids of a graphite austenite aggregate are distributed. He also says that if there is another type of mottled structure he would like to know about it. Perhaps the accompanying micrograph (Fig. *B*) will show that his generalization is not correct: it gives the mottled structure of a cooling curve ingot prepared from the Scandinavian pig iron Vantit. If cooled sufficiently slowly such material would have given a structure consisting entirely of undercooled graphite. Other types of mottled structure are known and Professor Hultgren should beware of regarding his iron *C* as normal. In our experience it is quite abnormal but this difference of opinion is of secondary importance, and suggests either that two forms of the fine graphite exist or that it can form directly or indirectly.

The sharp angular outline of the areas of fine graphite will be noted from Fig. *B*. This might suggest, for instance, that the ledeburite formed first and the graphite eutectic subsequently. Alternatively, if the graphite eutectic formed first, why did it adopt an angular outline ? Perhaps its outline was contributed by a carbide from which it formed ? Thus we believe the matter more complex than the Swedish workers appear to have assumed; others contributing to the discussion may see that one may not generalize from the spheroidal pattern shown by Hultgren, Lindblom, and Rudberg.

Regarding the term 'degenerate' applied to eutectic structures, we do not quite agree with Professor Hultgren's definition. We agree that the repeat pattern characteristic of a eutectic does not occur when the eutectic is 'degenerate,' but the normally dispersed phase usually deposits on already existing primary phase of the same type. We also agree that the deposition is usually simultaneous but the continuous phase is allotriomorphic in the interdendritic positions. In the paper on Fe–P–C alloys it was the intention to show that the type of degenerate structure observed in which both phases of the eutectic were idiomorphic arose from simultaneous crystallization and not from successive crystallization brought about by undercooling. This latter process can occur, for instance, in hyper-eutectic Fe–C–Si alloys and cast irons—a deposition of hypereutectic graphite can be followed by a deposition of austenite in dendrite form and this in turn by the crystallization of a eutectic. It was intended to indicate that the presence of two phases idiomorphic in outline and representing each side of the eutectic could arise by simultaneous as well as by successive crystallization.

Dr. Riley infers from our analyses of separated carbides that cementite and the silico-carbide can have variable composition. We cannot agree that our results show this. It must be remembered that the carbides separated from alloys having 2·7–7% Si are a mixture of cementite and the silico-carbide, the proportion of the latter increasing with increasing silicon content. Even if the compositions of cementite and the silico-carbide were constant we should obtain a composition varying with silicon content for the mixture of separated carbides. The two carbides may have variable compositions but it is impossible to deduce this from our results. The work of Owen and his co-workers has shown that there is probably more than one silico-carbide but we are unable to answer Dr. Riley on the fixity of their compositions.

Dr. Riley also enquires about inverse chill in cast iron. In our opinion there are several forms of inverse chill, one of which is associated with undercooled graphite structures. We have explained this elsewhere. This particular form of inverse chill is the only one which can be readily distinguished from normal forms of chill and its occurrence is of great significance to the discussion on undercooled graphite formation.

In reply to Mr. Turner, our micrographs were taken with a Vickers Projection Microscope.

Dr. Allen points out that some explanation must be provided for the sudden increase in graphite nucleation rate after solidification if the indirect formation of undercooled graphite is to be believed. We feel that little is known about eutectic nucleation processes but would like to point out the following. The undercooled fine form of graphite arises from the solidification of relatively few eutectic cells, whereas the coarse form of graphite is associated with many relatively fine eutectic cells. We are concerned with the nucleation of the eutectic and not so much with the nucleation of graphite. Whereas in undercooled graphite structures eutectic solidification begins from a few points only, the individual graphite particles are very numerous. Clearly if undercooled graphite forms directly from the liquid, graphite nucleation is not the controlling feature but eutectic cell nucleation, which is quite different. However, nucleation is not necessarily the only process to be taken into account. Solidification is a nucleation and growth process and therefore the rate of crystallization might be a controlling feature. Undercooled graphite always forms under conditions demanding high eutectic-cell growth rates, *i.e.*, from few nuclei, or under conditions of rapid cooling. It is conceivable that the crystallization of iron carbide is able to satisfy such high growth rates whereas the crystallization of graphite does not.

Mr. Östberg shows a micrograph in which there seems to be evidence of graphite forming as a result of carbide decomposition. He infers that this is normal flake graphite arising from the decomposition of normal ledeburite. We question whether this is so. We have illustrated this form of graphite disposed around cementite on several occasions[1, 9–11] and have shown that it occurs in irons having free iron sulphide. Hultgren and Östberg do not seem to have seen our observations on this. We have shown that free iron sulphide apparently promotes the growth of graphite films at various interfaces—austenite/cementite and austenite/iron sulphide—and in fact we have shown that carbide decomposition by this process can be complete during solidification giving a final structure, different from but resembling undercooled graphite, which we have termed 'mesh' graphite. We feel that our earlier observations are pertinent to the subject of Hultgren and Östberg's excellent paper. For instance, our graphite films have probably formed, at least in part, when a substantial amount of liquid was present. Similarly, the heat-treatment temperatures and compositions used by the Swedish workers are such that

a liquid sulphur-rich phase and a liquid phosphorus-rich phase would be present during annealing. We would like to suggest that this liquid gives rise to the graphite films and that otherwise the combined effect of hydrogen and sulphur would have been to give graphite spherulites. On this same subject we are able to confirm the influence of hydrogen in promoting spherulite formation, demonstrated for the first time by the Swedish workers. Finally, we wish to point out that graphite films also form around carbides in some magnesium-treated irons.[12]

Mr. Hopkins in referring to p. 377 of our paper has misunderstood our point when we say that undercooled graphite areas frequently take their form from the carbide particles. We did not mean the disposition of the individual graphite flakes in the austenite but the external shape of the whole area of undercooled graphite. This was the purpose of our original Fig. 3*b*, but perhaps Mr. Hopkins will see our point more clearly from Fig. *B* reproduced here.

We would like to thank the contributors to the discussion for raising so many useful points. In case this reply so far has created a different impression, may we say finally that we feel that the indirect formation of undercooled graphite has not yet been proved or disproved. The Swedish experimental work was carried out very carefully but unfortunately on a material which did not have a completely undercooled graphite structure. The same technique with more suitable material might have been more convincing to us.

REFERENCES

1. H. Morrogh and W. J. Williams: *J. Iron Steel Inst.*, 1947, vol. 155, pp. 321–371.
2. J. T. Eash: *Trans. Amer. Found. Soc.*, 1941, vol. 49, pp. 887–906.
3. G. J. Shaw and V. Kondic: *Found. Trade J.*, 1953, vol. 95, pp. 473–478.
4. A. Berman and V. Kondic: *J. Iron Steel Inst.*, 1954, vol. 176, pp. 385–387.
5. J. E. Hilliard and W. S. Owen: *Ibid.*, 1952, vol. 172, pp. 268–282.
6. W. S. Owen: *Ibid.*, 1951, vol. 167, pp. 117–120.
7. H. Morrogh and W. J. Williams: *Ibid.*, 1954, vol. 176, pp. 375–378.
8. W. S. Owen and B. G. Street: *Ibid.*, 1952, vol. 170, pp. 241–243.
9. H. Morrogh: *Ibid.*, 1941, vol. 143, No. I, pp. 207P–253P.
10. H. Morrogh: *Ibid.*, 1946, vol. 154, No. 2, pp. 399P–408P.
11. W. J. Williams: *Ibid.*, 1950, vol. 164, pp. 407–422.
12. H. Morrogh: *Brit. C.I. Res. Assoc., J. Res. Dev.*, 1950, vol. 3, pp. 251–298.

DISCUSSION ON ROLLING MILLS

The discussion was based on a group of papers published in the *Journal* for April, 1954; the titles are given in the October issue, p. 161.

AUTHORS' REPLIES

Mr. **S. E. M. Norlindh** (Morgårdshammars Mek. Verkstads AB, Sweden) wrote: Mr. Hood asked for our comments on the comparison between continuous wire-rod mills and looping mills with high-speed repeaters. In the case of continuous mills for high-grade steels we would choose only the vertical- and horizontal-stand type provided with loop lifters. The main disadvantage with high-speed repeater mills is that they are fairly new and thus have not been operating long enough for an absolutely safe judgment to be made. We have also not had time to investigate all the possibilities of repeater rolling. Up to the present we have found the following advantages with high-speed repeater mills.

(1) Half as many motors are required, which means simpler electrical equipment and less chance of trouble caused by fluctuations in the electrical system
(2) Between the wire-rod trains automatic loop deflectors are used with adjustable loop length two or three times longer. Furthermore, if the speed is too low in the following wire-rod train, the loop can run into the whip channel and then gradually be caught during the pass-time. It is thus much easier and safer to set for a new size than in continuous mills with loop lifters. With the exception of the loop-deflector roller there are no movable parts
(3) There is no risk of stretching the rod; this results in better tolerances
(4) The amount of cobbles is probably less, but comparative figures are not available
(5) Samples can be cut from the tail end in each pass to check the section and the surface
(6) Lower capital costs.

We do not know if it is slightly easier or slightly more difficult to assemble entry and exit guides and repeaters, or if the risk of scratching the rod is greater or not quite so great in high-speed repeater mills. In a repeater mill the second stand of each wire-rod train has a larger roll diameter than necessary from the design point of view and by this means a larger lateral spread in this pass is obtained. This is of course a disadvantage but not so great a disadvantage as having each stand driven by a separate motor.

In Scandinavia we feel that alternating two-high trains with high-speed repeaters are much to be preferred when rolling high-grade steel. This can best be illustrated by mentioning that Fagersta built their wire-rod mill in accordance with the alternating two-high principle. Mr. Arthur Åhrén, who decided how Fagersta's wire-rod mill should be built, was previously rolling-mill superintendent at Hofors. Another illustrative example is Degerfors' rod mill, which in 1946 started a continuous wire-rod train consisting of two horizontal and two vertical stands, all of which are provided with loop lifters. To this wire-rod mill has now been added two alternating two-high stands as shown in Fig. *A*. Mr. Åke Wahlberg, who ordered this additional equipment, had previously been rolling-mill superintendent at Hofors and thus well knew the reasons just mentioned for and against repeater rolling.

As to Mr. Hood's question about the actual outputs achieved, Mr. Svane of Kanthal gives in Table *A* outputs from 1st October, 1953 to 23rd January, 1954, from 2½-in. square, 21 ft. 4 in. long, 440-lb. billets. A new furnace was just started up at that time, but the output has been increased now.

Christiania Spigerverk give the figures in Table *B*, taken at random from their statistics.

Mr. Hood asked how we make the oval from the roughing mill enter the small-section mill by itself. If the oval is bent in its path it turns upwards and thus enters by itself. This transference of the oval from the roughing train to the small-section train works well on

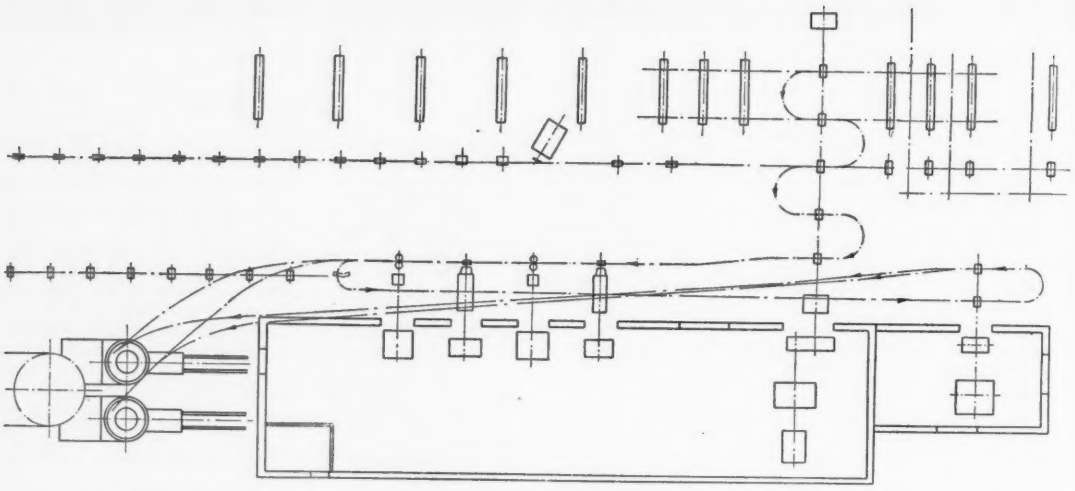


Fig. A—A 2-stand high-speed repeater rod mill which has been added to the 4-stand continuous wire-rod train at Degerfors

Table A

OUTPUTS AT KANTHAL

All outputs in metric tons

Dimension		Type	Average Output, tons/hr.	Maximum Output, tons/shift	Equivalent of Maximum Output, tons/hr.
in.	mm.				
0·315	8·0	Round in coils	10·3	66·2	12·7
0·393	10·0	" " "	14·1	125·3	14·7
0·861	21·9	" " "	17·2	140·5	18·0
0·622	15·8	Square in straight lengths	16·9	145·9	17·8

Table B

OUTPUTS AT CHRISTIANIA SPIGERVERK

All outputs in metric tons

Rolled Size, in. round	Carbon Content in Quality Electric-Furnace Steel, %	Approx. Finishing Speed, ft./min.	Billet Size, sq. in.	Billet Weight, lb.	Period	Output Rolled, tons	Output per Effective Rolling Hour, tons	Output per Total Hour, tons	Effective Rolling Hours per Total Hours, %
0·236	0·10–0·65	3140	3·15	330	1953, weeks 49–50	1290·7	9·42	6·33	67·12
					1954, weeks 13–14	1226·3	9·86	6·81	69·07
0·315	0·10	1860	3·15	355	1953, weeks 50–51	589·6	10·11	7·75	76·67
					1954, weeks 14–15	693·3	10·74	7·88	73·39
0·394	0·10	1860	3·15	420	1951, week 5	247·6	13·82	8·98	64·97
					1952, week 6	382·9	12·84	9·99	77·82
0·51	0·10–0·15	1220	3·15	450	1954, week 2	1387·5	15·60	12·50	80·11
					1954, week 19	1770·8	16·48	13·6	82·47
0·63	0·10–0·15	1220	3·15	420	1954, week 10	902·3	15·90	13·61	88·56
					1954, week 28	974·9	16·43	13·31	81·0
0·75	0·10–0·15	1220	3·15	420	1953, week 48	827·4	15·56	12·26	78·77
					1954, week 15	1201·0	16·86	13·12	77·80
0·98	0·10–0·15	1220	3·15	420	1953, week 32	1034·4	13·95	10·92	78·24
					1954, week 8	1176·5	15·58	13·26	85·07

soft qualities and also on spring steel but in the case of larger ovals and harder steel qualities it does not work. This problem is not yet solved but we are working on it.

Some years ago mills were built to transfer a square or round section to the small-section train by the method shown in Fig. *B*. The round section is preferable as the square section sometimes enters diagonally instead of flatly. The first end of the following oval will then be twisted a little, which may sometimes cause a cobble in the oval repeater. In the case of transferring a square or round section to the small-section train two passes will be positioned close to each other in the bottom pass of the third stand of the roughing mill and the sections cannot be set independently. This is such a great disadvantage that we have decided to transfer the oval instead and this method works all right at Frederiksvaerk in Denmark where spring steel is the hardest quality rolled, but it does not work with the harder qualities rolled at Söderfors because the oval tends to twist and stick to the pinch rollers.

With respect to Mr. Hood's question about the oval–round pass design, we have not yet had occasion to make such experiments at any mills other than at Christiania Spigerverk, where a round section is transferred to the small-section mill. For some time at Christiania Spigerverk a round section was used from the small-section train to the wire-rod train, but this is not used now as it gives too small reductions. As soon as possible we shall begin with these experiments on larger sizes where the number of stands is sufficient for small reductions.

With regard to Mr. Hood's remark that the crew will put the rollers of the roller guides too near each other, I will mention what happened once when rolling 0·2-in. (5 mm.) cable wire rod. The rollers were so tightly set that we got a reduction between the roller-guide rollers of 0·08 in. (2 mm.). The force from the repeater was sufficient to push the oval between the rollers and made the bar grip between the rolls. It is not advisable to set the rollers in the roller guide so hard that they grip the oval, but if the oval is kept steadily in the vertical position there will be no twisting stress from the rolls. For soft iron it is enough if the rollers in the roller guide touch the oval, but on hard steel qualities rolled by repeater the rollers must be set more tightly.

Mr. Hood asked about the tolerances of steel in straight lengths. I wish I had some diagrams for the maximum and minimum sizes measured on each bar for different sizes and for different tonnages of each size as this is the only really efficient way of showing what tolerances may be obtained in any given rolling mill. The normal tolerance on 1-in. round is ± 0·01 in. (± 0·25 mm.). If necessary the tolerances can be kept within ± 0·005 in., but the grooves must be changed more frequently and the rolls must be set more accurately. These narrow tolerances are of course more expensive to obtain as it requires more time to set the mill exactly and certain bars in such a case would have to be rejected. Practice shows that if you do not require narrow tolerances you will not get them as the rolling mill crew will not set the mill more accurately than necessary.

Mr. Stewartson asked about the finishing temperature in repeater rolling mills. When rolling merchant iron and 5-gauge rod it is about 950–1050° C. We have thus a temperature drop of about 200° C. from the furnace to the finishing temperature. These temperature conditions are about the same as those in continuous wire-rod mills. For harder steel qualities the finishing temperature will, however, be higher. For example, when rolling $\frac{3}{16}$-in. (7 mm.) rod containing 0·35% C we obtained a finishing temperature of about 1000° C. With Nimonic, *i.e.*, 80/20 Ni–Cr, the finishing temperature was about 1150° C. More heat is thus rolled into the bar when

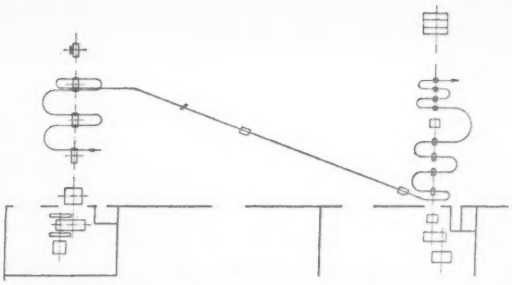


Fig. B—Former method of transferring a square or round bar to the small-section train with 4 + 4 stands. For comparison with present-day practice *see* Fig. 3*b* of original paper

rolling harder steel qualities. Of course we should like to have a shorter distance between the medium-section and small-section trains but the oval to be transferred to the small-section train is relatively large and therefore the temperature will not drop so much there. The distance is determined by the lengths of bars to be rolled in the medium-section train. Between the small-section train and the wire-rod trains, and between the wire-rod trains, the bar runs mainly through double-walled tubes. The interior tube will then be hot and the bar is not exposed to any cooling worth mentioning. In one rolling mill we have, however, begun to convey cooling water between the outer and inner tubes so that the interior tube can be kept cold to decrease the finishing temperature. This may prove necessary for very hard steel qualities.

As several bars will be rolled at the same time in different stages there will be on the average about one and a half cobbles in addition to the ordinary cobble. We are, however, busy making two-strand repeaters, partly so as to be able to roll a longer time between the groove changes and partly to have one strand free in case of cobbles.

When we give tolerances, *e.g.*, ± 0·004 in., we mean in Scandinavia that the deviation of the height, width, or diagonal measurements may never, on any part of the bar, exceed this amount. I have never heard of any other kinds of tolerance definitions.

We in Sweden seldom use grooves for 5-gauge high-grade wire rod for more than 30 tons a groove but conditions have changed considerably lately as the quality of the rolls has been improved. The frequent groove changes are made to avoid seams and not because of the tolerances, as these have less importance when the rod has to be cold-drawn. It is quite new for me to hear that such close tolerances can be kept in continuous wire-rod mills as ± 0·004 in. and even ± 0·003 in. on 0·2-in. (5 mm.) wire rod, and I must compliment Mr. Stewartson on having succeeded in obtaining such good tolerances in his Morgan mill. I have not seen anything comparable in any continuous wire-rod mill. I had believed that only repeater mills could obtain such good guaranteed tolerances.

That it is not always easy to secure such tolerances was proved recently when a customer bought 0·315-in. (8 mm.) rod for bolts and nuts from two new suppliers both of whom had new and modern mills. The rod supplied could not, however, be used because of too wide tolerances. On the other hand, the ordinary supplier who had a modern repeater rolling mill kept a tolerance of + 0 − 0·006 in. (+ 0 − 0·15 mm.), which could not be obtained by the other makers. Both in continuous wire-rod mills and in repeater rod mills

the temperature is to a large extent equalized so that a colder bar from the roughing mill will run at about the same temperature as the other rods in the finishing passes. Here the stiffness of the stands does not play such an important part as in a small-section train, where the temperature may vary. To take an illustration, at Hellefors two of the new type of stand were on a certain Sunday installed as finishing stands in the small-section train. On Monday afternoon the checking foreman told the superintendent that the tolerances of the finished steel had been much better than before. He did not know about the change of stands but could without difficulty notice on the finished steel that a considerable improvement had taken place. When rolling high-grade steel with various qualities and in small lots the rigidity of the stands has shown that the work of the crew has been facilitated and also much better tolerances on the finished steel have been obtained.

Mr. Thomson's question with regard to the cost of the new stands can be answered by telling him that the price for one stand of the new type is lower than one stand of the conventional type of the newest design.

Mr. Thomson asked whether we use twist guides for large orders. We never use twist guides when rolling rounds and squares with repeaters in the combined mill. Twist guides are, however, required when rolling broad flat sections and also for sections resembling squares, but it is always difficult to set the twist guides accurately enough to make the repeaters work reliably.

It was also asked whether roller guides with 6 rollers are preferable for larger sizes. The life of the roller-bearings in our larger roller guides is not critical. It is therefore suitable to use the smallest roller guides only from 0·2 in. (5 mm.) up to 0·3 in. (8 mm.) or possibly 0·35 in. (9 mm.) and to use larger roller guides for larger finished sizes. The new Morgan rolling mill at Domnarfvet has just changed the roller guides with 6 rollers to our design for the sizes $\frac{3}{8}$–$1\frac{1}{4}$ in. as it was found that these work better.

It is well known that the yield in high-grade-steel rolling mills with small tonnages of each size is much less than in mills rolling merchant iron in large quantities. In Sweden we understand the yield as the checked, approved, and despatched weight in relation to the weight of billets put into the furnace. We thus take into consideration not only the scale-loss in the furnace and the rolling mill but also the cropped ends, the cobbles in the mill, the cut-off ends, and the rejection of coils or bars which show seams, overfills, or tolerance or other faults. In Sweden we use as a rule a rather big section of billet which also influences the yield. For example, at Kanthal, where the billet size was changed from $3\frac{3}{4}$-in. (95 mm.) square, 100-in. (2·5 m.) long, and 330 lb. (150 kg.) in weight, to $2\frac{1}{2}$-in. (65 mm.) square, 21 ft. 4 in. (6·5 m.) long, and 440 lb. (200 kg.) in weight, the yield seemed to increase about 2% owing to less scale, less trouble with piped billets, and less cropping during the rolling. I regret that we have not yet been able to roll in the same way and under the same conditions as in the continuous Morgan mills. Hitherto 0·2- and 0·24-in. wire rod has been rolled for only about 3 weeks at a time four times a year in the combined mills.

The high yield figure of 96% mentioned by Mr. Thomson is much to be admired, but I have only on rare occasions and for small quantities seen such high yield figures in the rolling reports and then I have as a rule dismissed them as being the result of faulty weighing. The remaining 4% only leaves about 1·5% for scale deduction, 0·2% for cropping when rolling, and 2·3% for cobbles in the rolling mill and at the checking before despatch. Considering that certain furnace charges can be rather faulty in regard to pipe and flaking and thus cause cobbles in the rolling mill, I find it difficult to believe that it will ever be possible to obtain such good yields in Scandinavia when rolling merchant iron. These conditions are different in the combined mill so that we get approx. 2·5–3% for scale deduction and 0·5% for cropping.

At Domnarfvet's Morgan mill the yield after 2 years' running is 93% for wire rod and 94% for bars. Because of the conditions prevailing in Sweden they do not think it possible to reach a higher yield than 94–95% for wire rod and 95% for bars. These conditions are mainly:

(i) Shorter runs of each rolled size

(ii) As they are making the billets themselves they think that it is cheaper to roll out a billet with a certain amount of pipe than to scrap it

(iii) About 90% of all bars are nowadays delivered in exact lengths with the normal tolerance, *viz.*, 33 ft. + 4 in. − 0 in., and therefore the scrap at the cold shear is greater.

I do not think that repeater mills are worse in respect of cobbles caused by pipe and flaking than the continuous mills. At any rate I have seen many bars with severe pipe pass through repeater mills which would never have passed through a continuous rolling mill without cobbling. As the billet size and weight and the furnaces and also the rolled products are different in the combined mill it will be impossible to reach so high a yield as 96%.

A more accurate comparison would be possible if we could procure reliable figures for the percentages of cobbles and compare them with those for the continuous mills. Such figures are difficult to get, but both Mr. Pihlblad and Mr. Riddervold have quoted about 1% of cobbles for soft qualities.

With regard to Mr. Thomson's statement about the reductions in Morgan mills, it can be mentioned that in one of the newest Morgan mills which was put into operation in 1952, at Domnarfvet, 21 passes are used when reducing from 2-in. square to 0·216-in. wire rod. Square–oval roll passes are used except in the 6 continuous wire-rod stands, where oval–round roll passes are used. Mr. Riddervold has compared the reductions on his mill with those of the Domnarfvet Morgan mill.

On the subject of the tolerance allowance on bolt iron, Mr. Svane of Kanthal tells us that in his mill he guarantees the following tolerances:

Dimension of Rounds, in.	Tolerance, in.
0·275–0·4	+0 −0·006
0·4–0·7	+0 −0·007
0·7–0·8	+0 −0·008
0·8–1·2	+0 −0·013
1·2–2·0	+0 −0·015

I myself wanted Fagersta's wire-rod mill arrangement (Fig. 12*b* of the original paper) to be in accordance with Fig. 12*a*, *i.e.*, similar to that in the combined mills, but they did not think it mattered. Now they feel that an arrangement as in Fig. 12*a* would have been better.

Mr. Langen asked about the use of repeaters on hard steel qualities. Normally we roll all qualities by hand down to 1·9-in. square in the first stand. The oval after 1·9-in. square is transferred with repeater to stand 2 and 1·42-in. square is transferred with repeater from bottom position to top position in stand 2. The largest square of high-speed steel that has been rolled with a repeater with 32-in. (800 mm.) span is 1·61 in. (41 mm.).

We have not yet made any repeaters with rollers, but

all repeaters are made of cast iron to get a smooth contact surface and to avoid scratches.

Mr. Langen pointed out that the roll diameters in stands 5 and 9 are very large in relation to the bar. Of course we get an abnormally large lateral spread in these passes, and the groove diameters of the ovals must then be adjusted to obtain the desired reductions. Notice that pass data in Fig. 2 of the original paper are given for high-grade steel with short runs of each size. Recently a rolling mill has been sold which will mostly roll 5-gauge high-grade wire rod. This mill has consequently been provided with four wire-rod trains and stand 5 is not used when rolling rod. By this means the billet weight can be increased because of shorter loop growths.

The roll diameter in stand 9 can of course be reduced if you insert one more driving gear. This is naturally a matter of capital cost. The end must in this case justify the means, in order to ensure that all owners of high-grade steel mills, even those with a small annual output, will be able to have a good rolling mill with a large range of product.

Mr. Langen asked if we use special pinion stands in the small section and wire-rod trains. Three-high pinion stands of conventional design are used with a pitch diameter suitable for the roll diameters in the nearest two-high stand. In the following two-high stand with larger roll diameter the bottom roll is driven with a long coupling spindle direct from the bottom pinion gear, thus making the inclination reasonable.

Pinch rollers to pull the tail end from the finishing stand on to the coilers are not required at high speeds above 2400 ft./min. (12 m./sec.) because of the pulling force caused by the centrifugal force of the coil on the reels (*see* Fig. 11 and the formula at top of p. 399 of the paper).

Mr. **Axel Leufvén** (Svenska Kullagerfabriken AB, Sweden) wrote: Mr. Hood asked about the limiting speed for multi-row cylindrical roller-bearings in cold strip mills. This limit depends on the bearing size, the bearing load, and the lubricant which is used. In general, we reckon with a maximum permissible speed of

$$n = \frac{70{,}000}{d} \text{ r.p.m.}$$

where d = the bore of the bearing, in mm. For low loads the speed may be somewhat higher and for very high loads it should be lower.

In the 4-stand cold strip mill at Munkfors, material for amongst other things razor blades is rolled. The maximum speed is 300 r.p.m. I do not know the figures for the tolerances which have been attained but I know that Munkfors are highly satisfied with the results and that the mill, despite its negligible deflection, evens out the thickness variation on the ingoing strip considerably better than mills previously used.

Mr. Craig asked if it is possible to dismantle bearings mounted on a cylindrical seating by the oil-injection method. The oil-injection method can very well be used for bearings with cylindrical bore but its application is of course not so easy as when a tapered bore is used. A withdrawal tool must be used, with the help of which the bearing can be pulled off quickly when the edge of the inner ring has passed the supply duct for the oil. The withdrawal must be executed so quickly that the oil between the inner ring and roll neck does not have time to disappear. When mounting the application shown in Fig. 23, the inner ring is heated with the aid of an electric element which is placed in the bearing bore. The bearing can thus sit in its housing, and after heating up the inner ring the housing with bearing is pushed on to the roll neck. The use of bearings with cylindrical bore is not suitable in cases where mounting and dismantling must be carried out very often.

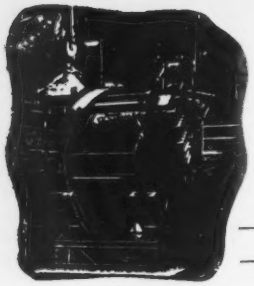
Regarding Mr. Thomson's question as to the accuracy attained in pre-stressed stands as compared with modern conventional stands, I would refer to what I have just mentioned regarding the cold-rolling mill at Munkfors and to Mr. Pihlblad's paper. Comparative tests of hot-rolling of wire rod have not been made, and probably would be very difficult to make, since the tolerances are dependent on so many factors. It should, however, be clear that the possibilities for accurate rolling are increased with increasing stiffness of the stands. The price per lb. for pre-stressed stands is higher than for stands of conventional design but in general the total weight is much less.

Mr. **K.-E. Pihlblad** (Fagersta Bruks AB) wrote: Mr. T. W. Hood asks for the output of this mill which is using high-speed repeaters, and the percentage of cobbles. In the Fagersta wire-rod mill the output is 90 tons/8 hr. for mild steel and 75 tons/8 hr. for special steel. The percentage of cobbles for mild steel is 0·42 in the form of direct cobbles, and 0·63 in the form of following cobbles caused by the following wire being already in the mill. The loss of time is about 3–5 min. For special steel the percentage of cobbles is 0·1 and 0·15. Twist guides are not used in the Fagersta mill, but between the guides or guide tubes and the repeater is a short twist guide to regulate the throwouts for different steel qualities.

Mr. R. Stewartson asks for the tolerances. The tolerances mentioned in my paper mean tolerances for the order. Naturally the tolerances for one coil are closer. The tolerances apply to all dimensions round the bar but the differences between the largest and the smallest diameter must be within two-thirds of the total tolerances for every bar.

Naturally the close tolerances are not only relative to pass life but also to the accurate adjustment of the rolls and the small deflection in the strands. In order to get the tolerances round the bar, it is necessary to change the pass fairly frequently, but it is important to remember that a change of pass takes only 3 min., and that the first wire after changing must be within the tolerances. The pass life in Fagersta is about 40 tons with good rolls.

Mr. M. Langen remarks that the distance between stand No. 19 and the coilers is considerable. That is done in the layout so as to be able to put in more stands if necessary when rolling smaller dimensions or rolling with higher finishing speed. No pinch rolls in front of the coilers are required.



AFFILIATED LOCAL SOCIETIES

LINCOLNSHIRE IRON AND STEEL INSTITUTE

Use of Cold Coke-Oven Gas and Pitch-Creosote Firing on Tilting Furnaces

DEVELOPMENT AT APPLEBY-FRODINGHAM

By W. Jackson, A.I.M.

SYNOPSIS

The change-over from mixed-gas firing to cold coke-oven gas and pitch-creosote firing at Frodingham melting shop is described. Fuel, refractory consumption, and output rates are compared with the different methods of firing for two different furnace designs. Increases in the sulphur burden and furnace oxidation rates are noted during the change in firing practice, and important output gains are recorded. 960

THE Frodingham melting shop consists of two 300-ton capacity steel furnaces and one 600-ton active mixer. It commenced operations in November, 1947, using mixed coke-oven and blast-furnace gas as fuel. A description of the plant and the results obtained were reported in the *Journal of The Iron and Steel Institute*.[1]

PITCH-CREOSOTE PLANT

To cover the possibility of fuel shortages, standby facilities to enable pitch creosote to be used were installed shortly after the plant started.

Pitch creosote is received in rail or road cars. It is pumped by either of two steam-driven horizontal duplex pumps, size 6 in. × 6 in. × 8 in., with a capacity of 5000 gal./hr. each, into two welded, mild-steel tanks with a capacity of 100,000 gal. each.

The pitch creosote in the tanks is maintained at 60° C. and is circulated round the melting shop in a ring main by one of two steam-driven horizontal pumps, each with a capacity of 1600 gal./hr., against a pressure of 175 lb./sq. in. and with a steam pressure of 140–180 lb./sq. in.

The pitch creosote is normally circulated in the 4-in. ring main at a pressure of 140 lb./sq. in. A constant pressure is maintained by a pressure-regulating valve; any pitch creosote pumped beyond requirements passes this valve and is returned to the tanks. About 20% of the pitch creosote circulating in the ring main is drawn off to the furnaces and passes through strainers and heaters fitted at each furnace. It is heated to 90–100° C. and then passes to either end of the furnace by means of steam tracered pipes. A similar route is followed by the steam supply used for atomization, which is supplied at 120 lb./sq. in. pressure and with a small amount of superheat. By experience, it has been found that maintenance of lagging and tracering must be of a high standard when using pitch creosote.

The pitch creosote used has the following characteristics:

Coal-tar fuel	200–250° F.
Equiviscous temperature	26° C.
Density at 15° C., g./c.c.	1·18
Pumping temperature	60° C.
Atomizing temperature at 100 sec. (No. 1 Redwood viscometer)	100° C.
Net calorific value, B.Th.U./lb.	16,200
Sulphur content	0·75%

Carburetting of Mixed Gas

Advantage was taken of this standby plant to carburet the mixed coke-oven and blast-furnace gas, with the addition of 40 gal. of pressure-atomized pitch creosote per hour, introduced into the gas stream at the back of the gas port. Formerly, good luminosity of the mixed-gas flame in the furnace depended upon the degree of preheat given to the gas in the checkers. The preheat was not so critical, however, when pitch creosote was added to the mixed gas, and the opportunity was taken to reduce the gas-port area and get a higher velocity of gas

This paper was presented at a meeting of the Lincolnshire Iron and Steel Institute held on 23rd March, 1954.

Mr. Jackson is Melting Shops Manager at the Appleby-Frodingham Steel Co., Scunthorpe.

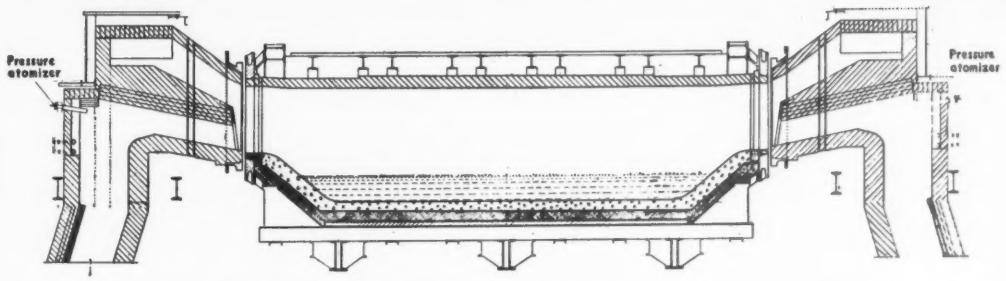


Fig. 1—Position of pitch-creosote pressure atomizer in mixed-gas furnace

into the furnace, with beneficial results. (The reduction in gas-port area was from 4·3 to 3·0 sq. ft.) This method is still used on the mixed-gas-fired furnaces on Appleby melting shop and is illustrated in Fig. 1.

The principle is to force heated pitch creosote through swirl passages in a pressure-atomizing nozzle, the resulting fine mist of pitch creosote being carried down the gas port by the preheated mixed gas. Trouble was experienced with choking of nozzles and pitch creosote passing to both ends of the furnace. Finally, the present method incorporating non-return valves and 'dead end' steam was designed, and, provided that maintenance of the lagging and non-return valves is kept at a high standard, an output gain of 6% is made over straight mixed-gas firing.

COLD COKE-OVEN GAS AND PITCH-CREOSOTE-FIRED FURNACES

In May, 1951, attention was drawn to the need to prepare for necessary alterations in the gas balance of the works as a whole when the second battery of coke ovens, to be fired with blast-furnace gas, came into operation later in that year. It was clear that there would be an excess of coke-oven gas, but insufficient blast-furnace gas for full mixed-gas firing of all furnaces, and it was decided that the most advantageous balance would be achieved by the use of 70% cold coke-oven gas in conjunction with 30% pitch creosote in some of the furnaces. The quantity of pitch creosote to be used was sufficient to replace the blast-furnace gas normally used with mixed-gas firing.

The first furnace to be fired with a combination of coke-oven gas and pitch creosote went into operation in August, 1951, at Frodingham melting shop, followed by the second furnace on that shop in September. A third furnace followed at Appleby melting shop in January, 1952.

It is the purpose of this paper to set out the development of, and the results achieved with, this type of firing on Frodingham melting shop.

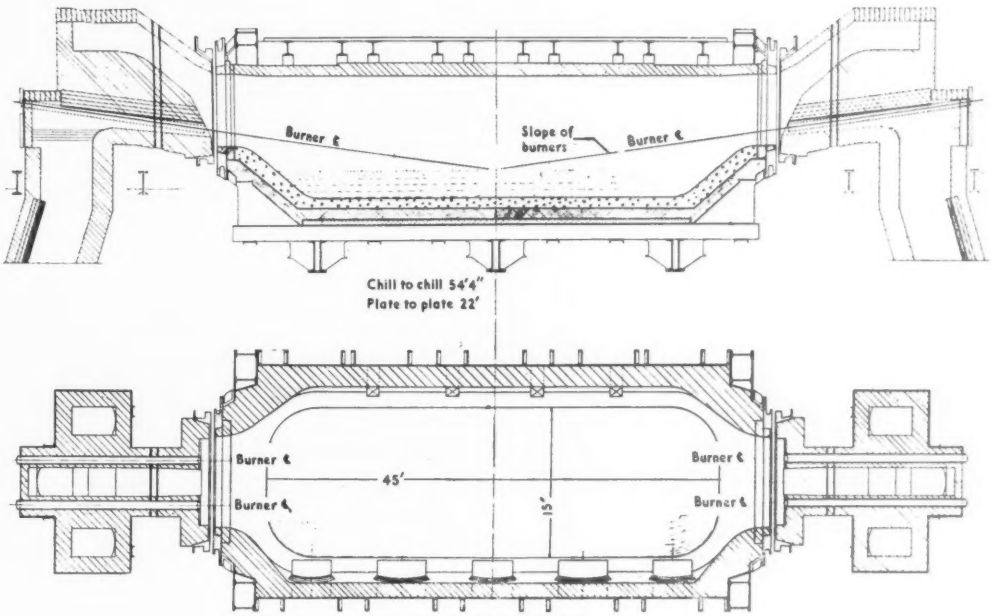


Fig. 2—Position of burners

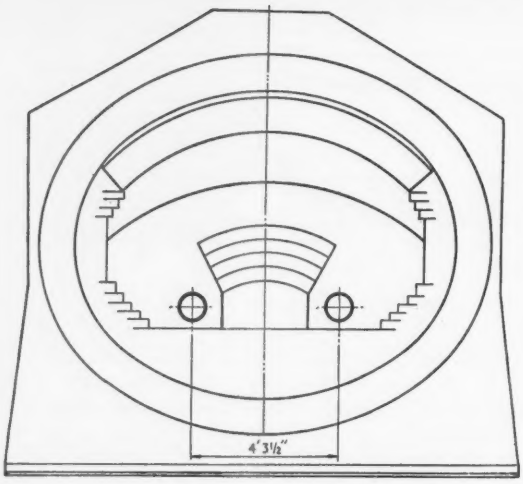


Fig. 3—Position of burners at side of gas port

Design Principles

As coke-oven gas and pitch creosote had not been used before, much information was sought and received from various technical papers and operators at other plants. The present operators wish to express their indebtedness at the outset for the generous assistance they received in this respect.

The first burners were designed, made, and installed in a period of 10 weeks by a team of fuel engineers, drawing office staff, plant technicians, and engineers working in close co-operation. The following principles were used:

(i) No alteration of the furnace design would be made, so that, if necessary, the furnace could revert to mixed-gas firing at short notice. The burner had to traverse the full length of the gas port (a distance of 20 ft.) and would be considerably longer than any known existing burner in use at other plants.

Furthermore, it was not known if a burst gun could be changed successfully during a furnace campaign owing to:

(*a*) Its long length and weight

(*b*) The restricted space between furnace blocks

(*c*) The removable slice at the nose end of the block.

Other decisions on design were such that one gun would not successfully fire the furnace, and it was conceivable that the furnace might have to revert to mixed-gas firing.

(ii) There would be two burners at each end of the furnace, set in the gas-port walls (Figs. 2 and 3). This would give maximum flame coverage of the bath and good combustion conditions.

(iii) The coke-oven gas should supply 70% of the heat required, 30% to be supplied by pitch creosote (90 gal./hr.).

(iv) The pitch creosote should be introduced above the cold gas nozzle, as it was felt that this would assist in keeping the coke-oven gas off the roof. Consideration was also given to other positions for introducing the pitch creosote.

(v) It was considered that the velocity of the coke-oven gas from the burners would be a critical factor in the successful operation of the furnace, and there was not much pressure available (28 in. W.G.) with which to achieve it. It was decided, therefore, to fix the gas nozzle size so that a high velocity would be achieved at average rates of flow, even at the sacrifice of some maximum flow of gas.

(vi) The atomization of the pitch creosote should be as simple as possible.

DEVELOPMENT OF BURNERS FOR CONVENTIONAL FURNACES

Figure 4 illustrates the original design of the burner (designated Mark A). It consisted of a 3-in. central gas pipe enclosed in a 20-ft. long, 8-in. dia. water cooling jacket, the whole assembly being 21 ft. 4 in. long. Cooling water was fed to the hot end of the burner through positioning vanes which held the gas tube in the centre of the 8-in. pipe. The vanes stopped 6 in. from the delivery end of the burner to allow good water distribution on the end plate. The pitch creosote was introduced above the coke-oven-gas outlet by means of a $\frac{3}{4}$-in. carrier pipe, surrounded by a $1\frac{1}{2}$-in. dia. pipe to act as a shroud and prevent cooling of the oil–steam mixture on its passage through the water jacket. The pitch-creosote nozzle was $\frac{29}{64}$ in. dia. and made of mild steel.

Details of the pitch-creosote nozzles and back-end atomizer are shown in Fig. 5. In the main, little

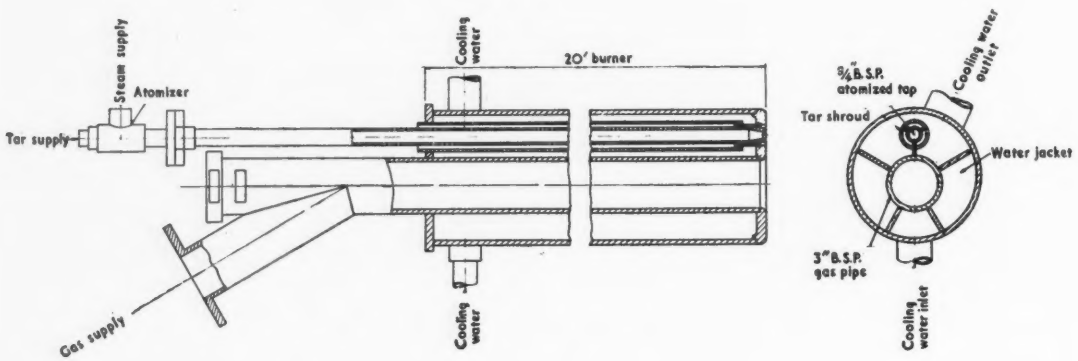


Fig. 4—Burner Mark 'A'

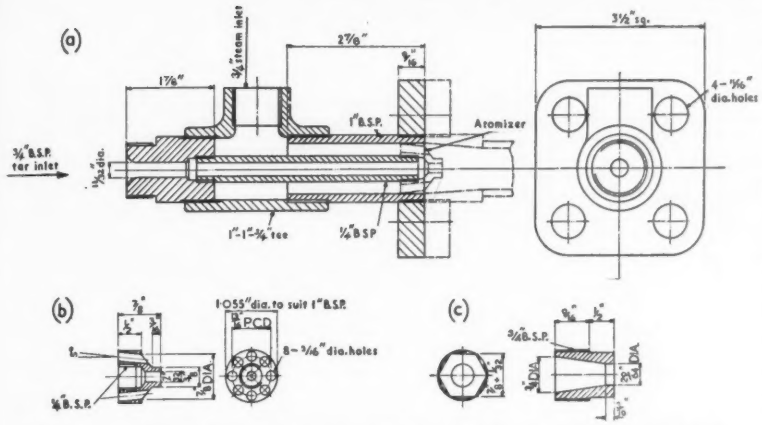


Fig. 5—(*a*) Atomizer body ; (*b*) atomizer (mild steel) ; (*c*) tar nozzle (steel)

alteration has been made in the design of this part of the equipment. Because of the necessity for cleaning at each reversal to keep the pitch-creosote nozzle clear of coke, and owing to the erosion effect of pitch creosote, stainless-steel nozzles were substituted for mild steel and these have maintained a better shape. This is particularly important, as the long length of the burners and the difficulty of changing them in the limited space available prohibited burner changing merely to correct a worn nozzle.

The supply of 45 gal. of pitch creosote to each nozzle was troublesome, but eventually by the use of restriction plates in the supply lines to each burner, a steady flow of steam and pitch creosote was maintained to each burner. Each nozzle was found to be capable of passing a range of 40–90 gal. of pitch creosote per hour, with atomizing steam varying from 6 to 14 lb./gal.

It was found, however, with the coke-oven gas pressure available (28 in. W.G.) that the maximum flow of gas from each end of the furnace through two burners at 70,000 cu. ft./hr. was not high enough to keep the furnaces working at maximum capacity. The nozzle velocity of the gas was 230 ft./sec. at 35,000 cu. ft./hr. per burner.

An improved type of burner was made for the next furnace to be equipped with this type of firing. Figure 6 (Mark B burner) shows the gas pipe enlarged to 4 in. for a distance of 18 ft., and in the last 2 ft. reduced to 3 in. dia. at the burner end. Coke-oven gas valves and flexes were increased to 4 in. dia., and the gas pressure increased to 37 in. by the commissioning of a modified booster fan. The cooling water was led through pipes to the nose of the gun, and the use of the centring vanes for this purpose discontinued. The maximum flow of gas at each end of the furnace was now found to be 115,000 cu. ft./hr. with a nozzle velocity of 380 ft./sec. Increasing the flex valves and Y-pieces of this burner raised the maximum flow to 130,000 cu. ft./hr.

Difficulties were experienced in keeping the gas nozzle clear of a deposit which accumulated for a short distance inside it, and which rapidly cut down the maximum flow of gas. Cleaning is now carried out with a special scraper immediately before charging commences when maximum gas flows are required; the later build-up in the gas nozzle does not unduly affect the furnace as its demand for gas is reduced to some extent as the charge proceeds. In practice, it assists in maintaining a higher velocity throughout the charge than would otherwise be the case.

Pressure tests on the burner indicated that increased gas pressure at the nozzle would be achieved by the use of 5-in. valves and flexes and increasing the gas pipe down the burner to 5 in. dia. for 18 ft. This would allow a gas-nozzle diameter of 2⅓ in. to be used, giving a nozzle velocity of 490 ft./sec. with a maximum flow of 103,000 cu. ft./hr. without alteration to the existing pressure. The outside diameter of the burner assembly has to be limited to 8 in., owing to the necessity—if heat losses or frequent bursts are to be avoided—to keep an adequate refractory covering over the 20 ft. length of the burner. This problem

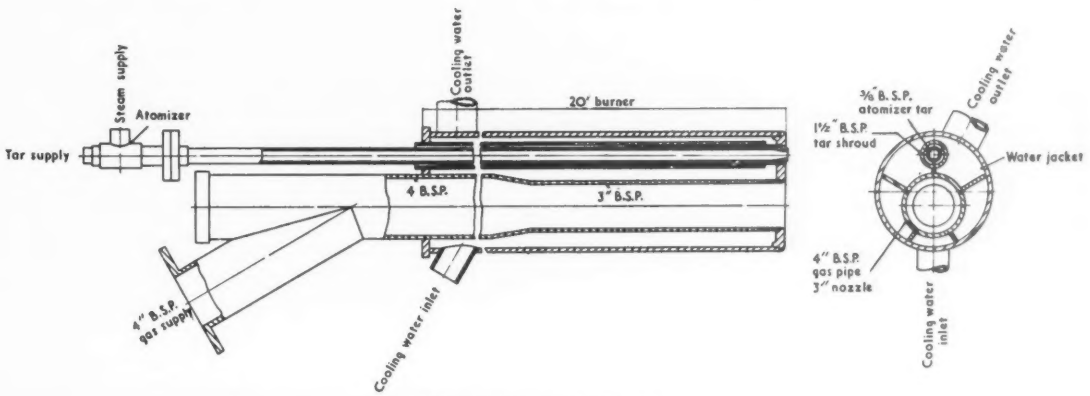


Fig. 6—Burner Mark 'B'

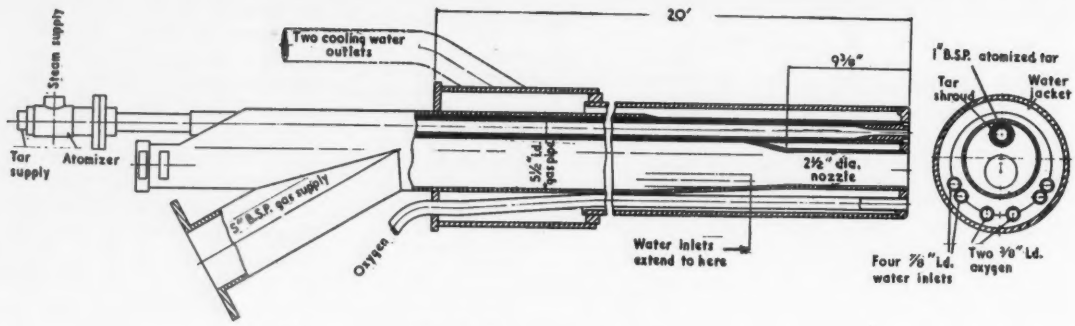


Fig. 7—Burner Mark 'C'

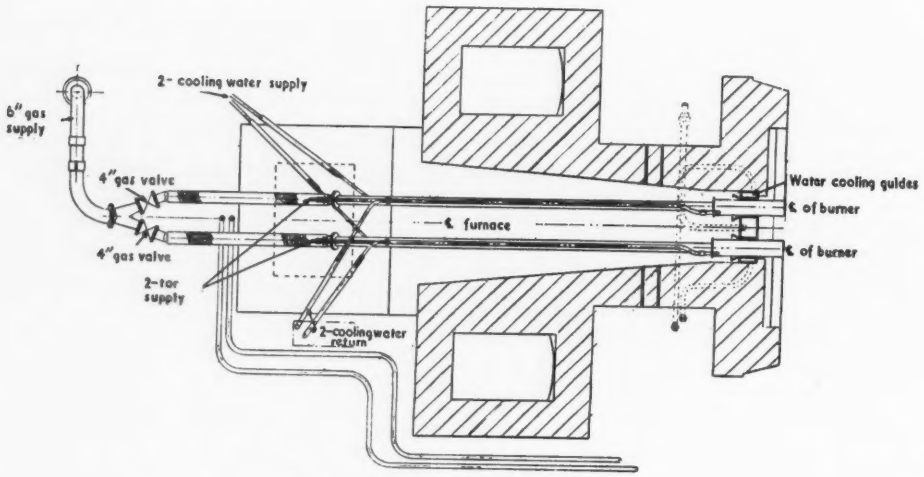


Fig. 8—'Doghouse' type port end

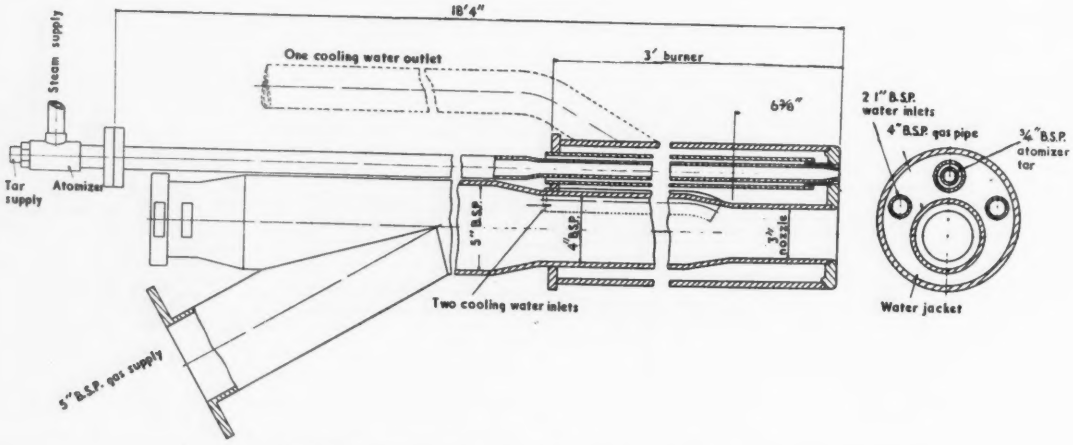


Fig. 9—Short burner for use with 'doghouse' type port end

Table I
COOLING WATER LOSSES

Type	Number per Furnace	Burner Water, gal./min.	Heat Loss in Cooling Water, therms/hr.
Long burners (used on furnaces of conventional design)	4	30	19·6
Short burners (used with 'doghouse')	4	24	5·2
Gun housing for short burner	2	40	2·0
Total for 'doghouse' design	...	...	7·2

has now been tackled by the design (Mark C) shown in Fig. 7. The pitch-creosote carrier pipe had now to run inside the gas pipe for 18 ft., thus allowing the pipe to be increased to 5½ in. dia. and achieving a further reduction of pressure loss.

Considerable difficulties were encountered in the construction of this burner as originally designed. The space for the passage of water-cooling pipes to the nose of the burner was limited, and it was now desired to incorporate two oxygen-supply pipes in the burner. The area of pipes emerging from the back plate was such as to leave little room for brazing and welding joints. This was overcome by expanding the 8-in. dia. pipe to 10 in. for a short distance outside the furnace, and using thin copper pipes to carry the water to the nose instead of the flattened steel pipe originally proposed.

Burners of this type have recently been installed in one of our furnaces and, although it is too early as yet to make any positive statement, they appear to be operating satisfactorily.

Burner Designed for Furnace of 'Doghouse' Construction

All the previous designs of burner shown have been used in furnaces of conventional design without the necessity for any alterations of the furnace structure. The only alteration made from a mixed-gas furnace design was to narrow the gas uptake by 9 in. to get more refractory cover over the burners.

One further burner was developed, however, for use on a furnace which had a 'doghouse' construction and a burner housing to receive the burners (Fig. 8), instead of building them into the brickwork of the gas-port walls. This burner design is shown in Fig. 9. Originally it had a 4-in. gas pipe for the greater part of its length, reducing down to 3 in. The gas pipe was later increased to 5 in., retaining the 3-in. nozzle. Appropriate alterations were made to the gas shut-off valves and connecting flexes. This burner had the advantage that it was easier to change when necessary, was easier to construct, did not distort in use, and gave considerably less heat losses. These points are shown in Table I.

The cooling-water heat losses have thus been reduced by 12·4 therms/hr. on this design. The operating results comparing the use of this type with the original design will be referred to later.

Table II shows the effect of the improvements made in the nozzle velocity of the various types of burners tried.

Pitch Creosote and Steam

At the same time that improved gas velocities were being sought, attention was given to the steam jacketing of the pitch-creosote supply from the heaters to the furnace end, and to increasing the steam supply to the atomizer. Close attention was paid to the lagging of these pipes to prevent solidification of the pitch creosote in the periods between reversal and to prevent condensation in the steam lines. Alterations were made to pipe sizes as follows:

	Original Furnace	Present Design
Oil to each end	¾-in. dia. steam-jacketed pipe	1-in. dia. steam-jacketed pipe
Oil to each burner	½-in. dia. pipe	½-in. dia. pipe
Steam to each end	1¼-in. dia. pipe	1½ (or 2-in.) dia. pipe
Steam to each burner	¾-in. dia. pipe (¾-in. flex)	1-in. dia. pipe (1-in. flex)
Steam at burner, lb./sq. in.	80	100

TRIALS WITH BASIC WALLS AND ARCHLESS COOLERS

At the same time that the use of cold coke-oven gas and pitch-creosote firing was being developed, trials were being made: (i) in the use of basic brick refractories to replace silica in the top of the uptakes; (ii) in the use of archless door constructions.

It is necessary, therefore, to consider these trials

Table II
GAS FLOWS AND NOZZLE VELOCITY

Burner	Shop Gas Pressure, in. W.G.	Diameter of Components, in.				Nozzle Velocity, ft./sec.	Max. Gas Vol.* through Two Burners, cu. ft./hr.
		Y-piece and Valves	Flex	Burner Pipe	Nozzle		
Mark A	28	3	3	3	3	230	70,000
Mark B	37	4	4	4	3	380	115,000
Mark B	37	5	5	4	3	425	130,000
	37	5	5	4	2¾	430	110,000
Mark C	37	5	5	5½	2½	490	103,000
Proposed	55	5	5	5½	2½	595	125,000
'Doghouse' type	37	4	5	5	3	425	130,000
	37	4	5	5	2¾	430	110,000

* Gas volume measured at 0° C. and 760 mm. Hg

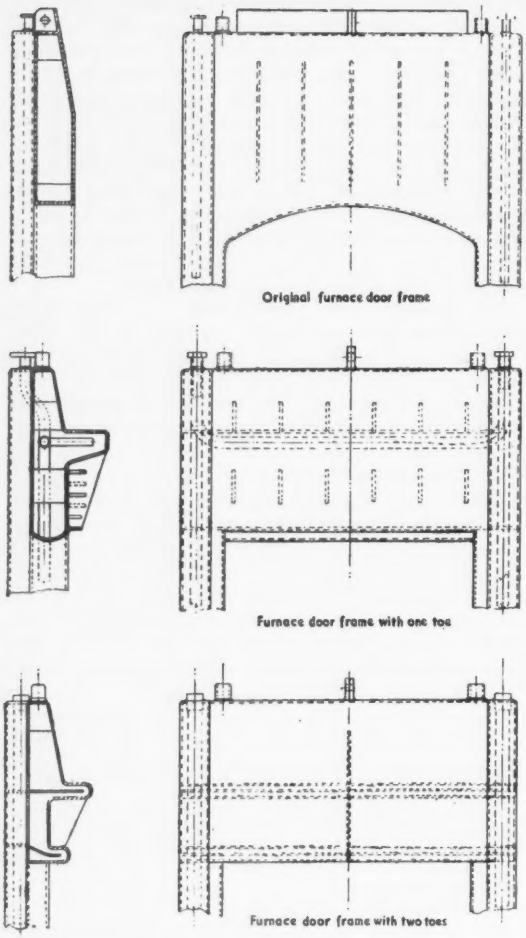


Fig. 10—Types of arch plate

before any output increases can be assigned to the use of cold coke-oven gas as fuel.

Experiments with Basic Bricks in Uptakes

The tops of the gas and air uptakes on these furnaces were formerly a very vulnerable spot, requiring frequent renewal of the silica brickwork with consequent delay to the furnace. In addition, the constant patching and renewal of this brickwork made increased volumes of slag in the slag pockets, requiring extra time for removal during furnace repairs.

The use of basic bricks has resulted in the virtual elimination of hot repair time in these target areas and considerably less material accumulating in the slag pockets, with some consequent increase in furnace availability.

Archless Doors

Trials were also made in the use of archless doors to reduce the number of repairs formerly carried out to arches: Fig. 10 illustrates the three types of arch plates used to date.

The arch repairs were reduced to one-third of those formerly experienced, but as a refractory lining cannot be maintained in these coolers very easily the practice at present is to build the new lining with a brick arch to maintain heat losses at a minimum until the brick arch fails, and then to install an archless plate.

The heat losses with the various types of arch-plate construction are as follows:

Cooler	Heat Loss, therms/hr.
Flat plate:	
Full brick arch	5·5
Worn ,, ,,	7
Single-toe archless:	
Full refractory covering	8
Worn ,, ,,	10–14
Double-toe archless:	
Full refractory covering	6·5
Worn ,, ,,	10–11

Little success has been achieved in maintaining refractory coverings over the single-toe plate. After three or four days rammed materials appear to fail

Table III
CORRECTED FURNACE OUTPUTS

Furnace	Mixed Gas: Output, tons	Mixed Gas: Time, weeks	Mixed Gas: Output Rate, tons/week	Cold Coke-Oven Gas: Output, tons	Cold Coke-Oven Gas: Time, weeks	Cold Coke-Oven Gas: Output Rate, tons/week
A	153,437	64·0	2395	137,446	51·0	2695
B	167,995	65·0	2585	137,925	51·4	2685
Total	321,432	129·0	2492	275,371	102·4	2690
			2492			2690
Add for losses due to:						
Arch repairs			68	Archless plates		23
Silica back walls			19	Metal case bricks		2
Direct metal			22	Direct metal		9
Iron quality			...	Iron quality		122
			2601			2846
Gain due to cold coke-oven gas firing, tons/week						245
Increase in output, %						9·7

and after five or six days even magnesite bricks hung on pegs are worn to 1 in. thickness. The double-toe plate was developed in an effort to maintain a better refractory covering and to reduce cooling water losses; in addition it permits a slightly larger door opening.

OUTPUTS WITH COLD-GAS FIRING COMPARED WITH MIXED-GAS FIRING

The results achieved in the first four campaigns of cold-gas firing are compared with the previous four campaigns of mixed-gas firing in Table III. Allowances are made for the improvements resulting from the use of basic bricks or magnesite tubes in the vulnerable areas of the uptakes, and the time saved on arch repairs by the use of archless plates. A correction is made for iron quality differences in the two periods.

The large correction for iron quality was necessary owing to the increased quantities of sulphur and silicon in the iron during the cold coke-oven gas period (*see* Table IV).

EXPERIMENTS IN FURNACE DESIGN

In the 2½ years during which cold coke-oven gas and pitch-creosote firing has been developed, simultaneous improvements have been made in other parts of the furnace. It is not possible, therefore, to allocate percentage increases of output obtained to each of the modifications in burner design previously mentioned, except in the case of furnaces of conventional constructions (Fig. 2) and the furnace design with a 'doghouse' to use the burner shown in Figs. 8 and 9.

The main differences between the two designs are as follows. The conventional furnace ('A') is as designed for mixed gas except that the gas uptake is 9 in. narrower. Water-cooled, coke-oven-gas/pitch-creosote burners are embedded in the gas-port walls at an angle of 8° and at 4 ft. 3 in. centres. They traverse the full length of the block—a distance of 20 ft. The burners at each end were spaced 4 ft. 3 in. apart and the furnace was supplied with forced air from the air checkers; natural draught air from the gas checkers passed down the gas port between the burners.

Furnace 'B' was modified by closing the front of the gas port with a water-cooled housing, passing the two burners down the gas port, which was now the equivalent of a 'doghouse,' then through openings at 1 ft. 8 in. centres in the housing. The gas uptake was sealed off at stage level. The burners are thus closer together and are supplied with air from above only.

In the first roof campaign the 'B' furnace operated at a high initial rate of production, but began to fall away rapidly as the air checkers became choked. Subsequently in this design a connection was made between the gas and air uptakes below stage level so that the waste gases could pass to the stack through the gas and air checkers, and some preheated air would be supplied under natural draught by the gas checkers, in addition to the forced air from the air checkers.

The design was now substantially a two-uptake furnace instead of a three, and to maintain approximately the same uptake area as before, the air uptakes were increased in area by building the outside walls 14 in. thick instead of 18 in. The total uptake area at either end was now 35·4 sq. ft. instead of 43·8 sq. ft.

In the construction of this type of block and uptake 12,000 9-in. bricks were saved, equal to 50 tons of refractory.

Table IV

METAL ANALYSES, %

	Mixed Gas		Cold Coke-Oven Gas	
	Into Mixer	Out	Into Mixer	Out
Si	1·04	0·21	1·10	0·26
S	0·088	0·076	0·095	0·082
P	1·54	1·15	1·51	1·17
Mn	1·01	0·44	1·00	0·47
C	3·43	2·77	3·27	2·68
Slag made on steel furnaces, cwt./ton	2·60		2·78	

The results achieved with the two furnace designs are compared below:

	'Doghouse' Design ('B' Furnace, Short Burner)	Conventional Design ('A' Furnace, Long Burner)
Production, tons	219,696	192,215
Working period, weeks	70·86	64·71
Output rate, tons/week	3101	2957
Availability, %	88·41	93·02
Fuel consumption, therms/ton	35·1	36·56
Fuel consumption, therms/hr.	616	633
Refractory, lb./ton	33·93	23·07

The two designs were operating simultaneously, and it was apparent that 'B' furnace was giving better outputs but was more severe on the roof, air-port roof, and uptakes. Roofs lasted nine weeks on 'B' furnace as against 11 weeks on 'A' furnace and thus required one extra repair per year. In addition, repairs took longer because, firstly, all the slag was accumulated in the air pocket instead of being spread over the gas and air as in a conventional furnace, so taking longer to clear; and, secondly, the thinner air-uptake walls on 'B' furnace needed more repair.

As a result of these factors the availability of 'B' furnace was considerably lower than that of 'A' furnace, although not to the extent indicated by the figures above; some correction on 'B' furnace should be made to cover a repair which was extended owing to a labour shortage, and also a large slag-pocket repair which was unique to 'B', but which will follow in due course on 'A' furnace. It is estimated that the availability when fully corrected will be not less than 1½–2% lower on 'B' than 'A' furnace. A correction applied for similar reasons indicates that 'B' design would use 5 lb. more silica per ton of ingot than 'A' furnace design.

Furthermore, 'B' furnace was equipped for part of the period with a remote control of the gas reversal, whereas 'A' furnace was manually reversed. The remote-controlled reversal of the gas from end to

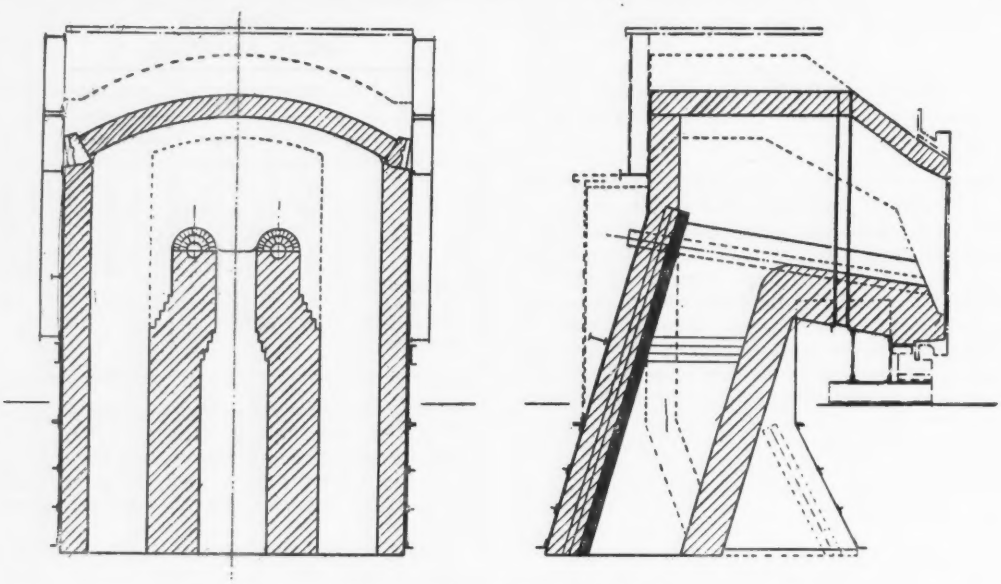


Fig. 11—Present design of cold coke-oven gas/pitch creosote furnace

end was performed much faster than when the men had to walk to one end to shut the gas off and then to the other end to turn it on. Comparative reversal times are:

	'A' Furnace (Manual)	'B' Furnace (Remote)
Fuel off completely, min.	0·28	0·35
Furnace on ½ fuel (pitch creosote), min.	0·70	0·07
Interval before furnace on full fuel, min.	0·98	0·42

With a 15-min. reversal period and making allowance for the long part-fuel period on 'A' furnace, the 'B' furnace gains, say, about 0·25 min., which should give it an advantage of 1·6% greater output and a lower fuel consumption in consequence. In addition, 'B' furnace had the advantage of a newly installed bottom with consequent less fettling delays.

Table V shows the annual outputs of each furnace and does not give any marked indication of superiority of the 'B' furnace design over the last two years, especially when note is taken of the preceding remarks.

It was finally concluded that more annual production could be made cheaper and more consistently on 'A' than on 'B' furnace. Further modifications have now been made to 'B' furnace, as shown in Fig. 11. This trial has only been proceeding for a comparatively short period, but very encouraging results have so far been achieved, the furnace having run for 11 weeks at an average of 3490 tons/week with a maximum make of 4509 tons in a week. The main feature in this design is that the gas uptake has no gas port or 'doghouse,' thus spreading the slag between gas and air pockets, with a lowering of the air-port roof by 2 ft.; this lowering is made possible by the elimination of the brickwork of the gas arch.

Table V

ANNUAL PRODUCTIONS, TONS

	'A' Furnace	'B' Furnace	Total
7 weeks, 1947	14,741	13,128	27,869
53 weeks, 1948	109,170	114,710	223,880
52 weeks, 1949	113,648	112,513	226,161
" " 1950	116,606	123,496	240,102
" " 1951	112,313	115,964	228,277
" " 1952	130,563	129,923	260,486
" " 1953	148,797	150,672	299,469

METALLURGICAL CONSIDERATIONS

Steel-Furnace Mixtures and Oxidation

A study of the material consumptions used in the steel-furnace mixture indicates that the percentage of metal in the charge has increased concurrently with the use of cold coke-oven gas firing and that the percentage of oxides used has also fallen (*see* Tables VI and VII).

The increase in the proportion of mixer metal in the charge is due in part to the gradual improvement of yields in the rolling mills, giving less return scrap to the melting shops, and in part to the reduction of the proportion of oxides required for oxidation of the charge metalloids. The amount of oxide used has decreased from an average of 2·40 cwt./ton during mixed-gas firing to 1·93 cwt./ton in 1952–53 with cold coke-oven gas firing. Taken in conjunction with the increasing iron usage due to increased mill yields, which with mixed-gas firing would have demanded the use of more oxides, this decrease of oxides used by 0·5 cwt./ton of ingots indicates the extent of the increased rate of furnace oxidation caused by the use of cold coke-oven gas as fuel (*see*

Table VI

STEEL-FURNACE MIXTURE, CWT./TON

	1947–48	1948–49	1949–50	1950–51	1951–52	1952–53
Mixer metal	15·92	15·40	15·57	15·70	16·83	16·37
Cold and molten iron, etc.	0·28	0·93	0·71	0·68	0·29	0·44
Scrap	4·30	4·29	4·32	4·24	3·67	4·02
Total metals	20·50	20·62	20·60	20·62	20·79	20·83
Finishings	0·19	0·16	0·18	0·19	0·19	0·20
Oxides	2·35	2·44	2·39	2·33	2·01	1·93
Limestone	1·68	1·84	1·65	1·77	1·82	1·55
Dolomite	0·46	0·51	0·51	0·50	0·54	0·56
Slag	2·52	2·87	2·73	2·76	2·74	2·54
Scrap made	1·04	1·06	1·01	0·99	0·98	0·96

Table VIII). The iron formerly supplied by the oxide has to be replaced by more mixer metal.

The increase in furnace oxidation rate is thought to be caused by the increased velocity of the flame leading to a clearing of the slag from the surface of the metal, with a greater penetration of the flame into the scrap during charging; the increase also results partly from the greater difficulty experienced in removing sulphur in the later stages with the present type of firing.

Sulphur Problems with Cold-Gas Firing

The coke-oven gas from the Appleby-Frodingham coke ovens contains 650 grains of sulphur per 100 cu. ft. of gas. It has been found that when mixed with blast-furnace gas and preheated in steel furnace checkers, a considerable degree of desulphurization is achieved. When used cold in conjunction with pitch creosote (sulphur content 0·75 wt.-%) the SO_2 content of the waste gas is increased to 0·110%, compared with 0·04% with mixed gas. (Desulphurization

Table VII

MIXER MIXTURE, CWT./TON

	1947–48	1948–49	1949–50	1950–51	1951–52	1952–53
Hot metal	17·89	17·97	17·84	17·78	18·32	18·27
Skulls, cold iron, etc.	0·17	0·34	0·37	0·21	0·13	0·19
Scrap	2·01	1·82	1·87	2·15	1·67	1·72
Total metals	20·07	20·13	20·08	20·14	20·12	20·18
Oxides	1·07	1·04	1·06	0·90	0·95	0·99
Fluxes	1·11	1·10	1·06	1·10	1·19	0·95
Dolomite	0·14	0·19	0·21	0·20	0·17	0·14
Slag	1·76	1·71	1·56	1·74	1·74	1·60
Scrap made	0·09	0·13	0·08	0·14	0·12	0·18

Analysis, %

	1947–48		1948–49		1949–50		1950–51		1951–52		1952–53	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Si	1·09	0·23	1·06	0·24	0·94	0·21	1·07	0·22	1·08	0·27	1·07	0·26
S	0·080	0·072	0·081	0·074	0·074	0·066	0·091	0·079	0·095	0·081	0·080	0·075
Mn	0·96	0·48	1·00	0·50	1·00	0·45	1·01	0·45	1·01	0·46	1·02	0·46
P	1·53	1·16	1·53	1·17	1·52	1·17	1·55	1·16	1·51	1·17	1·42	1·10
C	3·47	2·88	3·48	2·86	3·52	2·88	3·41	2·64	3·27	2·69	3·25	2·73

Table VIII

FURNACE OXIDATION RATE

Type of fuel used	1948–49 Mixed Gas	1949–50 Mixed Gas	1950–51 Mixed gas	1951–52 Cold C.O.G. and P.C.*	1952–53 Cold C.O.G. and P.C.
Oxidation rate, cwt. oxide per hr., by:					
Bacon's method[2]	5·73	8·07	5·15	13·99	18·04
A.I.M.M.E. method[3]	10·43	12·61	9·82	19·35	23·58

* P.C. = Pitch creosote; C.O.G. = coke-oven gas

Table IX

COMPARISON OF SULPHURS WITH MIXED-GAS AND COLD COKE-OVEN GAS FIRING

Period	Charge S, %		Slag Off S, %		Pit S, %	
	M.G.*	P.C. and C.O.G.*	M.G.	P.C. and C.O.G.	M.G.	P.C. and C.O.G.
4	0·0738	0·0737	0·0559	0·0640	0·0433	0·0515
5	0·0635	0·0641	0·0492	0·0588	0·0381	0·0466
6	0·0808	0·0811	0·0566	0·0585	0·0451	0·0463
7	0·0805	0·0840	0·0553	0·0634	0·0424	0·0477
8	0·0791	0·0799	0·0560	0·0669	0·0434	0·0510
9	0·0655	0·0656	0·0518	0·0593	0·0390	0·0460
10	0·0670	0·0657	0·0508	0·0609	0·0385	0·0475
11	0·0708	0·0706	0·0545	0·0629	0·0411	0·0477
12	0·0635	0·0631	0·0487	0·0591	0·0366	0·0431
Average	0·072	0·072	0·053	0·061	0·041	0·047

* M.G. = Mixed gas; P.C. = pitch creosote; C.O.G. = coke-oven gas

of 50% is allowed for in checkers on mixed gas.) This is equivalent to an increase of 40–50 lb. of sulphur per hour entering the furnace.

This increase in sulphur burden in the fuel is reflected in the increased difficulty found in removing sulphur in the metal. Table IX contains the results of a recent investigation on Appleby melting shop where two cold-gas-fired furnaces are operating alongside five mixed-gas-fired furnaces. The investigation covered all the steel made in a period of 36 weeks, and includes 330,000 tons of ingots made with mixed-gas firing and 160,000 tons made with cold-gas firing.

It has been calculated from these results that to get the same final sulphurs in the steel with cold-gas firing as with mixed-gas firing, the slag bulk would have to be increased by 0·5 cwt. per ton of ingots.

As Frodingham melting shop was fully converted to cold-gas firing in a relatively short period, no such comparison was possible. Table X shows an increasing sulphur in the melting slag and tapping slag with the use of cold coke-oven gas on Frodingham melting shop.

Attention is being given to the economics of desulphurizing coke-oven gas as it is clear that further increases in output could be gained with a lower ingoing sulphur in the fuel. If consideration is also given to the difficulties experienced by the ironworks in making low-sulphur iron regularly, and to the national shortage of sulphur for acid making, the development of an economic process for the recovery of sulphur from steelworks coke-oven gas is most important.

Refractories

In the five years during which the plant has developed, continuous improvements have been made in the use of refractories, such as the use of basic bricks at the top of the uptakes.

Steel plates are now inserted at every third or fourth course in the front lining and cottered back to the furnace shell. This gives added stability and life to this part of the furnace structure.

In addition, Silcrete bricks or other super-duty silica bricks are used in zebra fashion in vulnerable patches of the roof, *i.e.*, over the taphole or splay corners. Arches are now built with tongued and grooved Silcrete blocks and roofs are now of ribbed construction and built entirely with tapered blocks, instead of square and side arch blocks as formerly.

Nevertheless, the change of fuel has materially altered the mode of roof wear. It is now uncommon

Table X

SLAG ANALYSES

	Melting Slag Analysis					Slag Off S, %	Tapping S, %
	S in Mixer Metal, %	S, %	CaO, %	Fe, %	$SiO_2 + P_2O_5$, %		
1948	0·075	0·225	47·8	8·52	26·54*	0·058	0·053
1949	0·066	0·220	48·05	8·16	26·61*	0·057	0·050
1950	0·070	0·226	48·15	8·50	26·39*	0·057	0·050
1951	0·081	0·268	48·50	8·07	26·64*	0·065	0·054
1952	0·083	0·325	49·80	8·50	25·82†	0·066	0·057
1953	0·076	0·29	47·90	7·80	26·75†	0·065	0·054
		Tapping Slag Analysis					
1950		0·335	49·0	12·4	21·61*		
1951		0·363	49·1	13·5	20·72*		
1952		0·432	49·8	14·0	20·49†		
1953		0·477	49·8	14·3	19·79†		

* Mixed gas. † Cold coke-oven gas.

Table XI
CONSUMPTION OF REFRACTORIES

	1947–49		1949–51		1951–53	
	'A' Furnace	'B' Furnace	'A' Furnace	'B' Furnace	'A' Furnace	'B' Furnace
Ingots made, tons	221,619	207,562	216,114	222,285	271,435	251,019
Brick, lb./ton ingots						
Silica	22·1	22·85	28·3	24·7	14·2	19·0
Firebrick	3·9	2·85	2·4	3·85	1·85	2·5
Magnesite	0·9	0·9	1·0	1·0	1·45	2·5
Chrome magnesite	4·0	3·7	4·3	4·4	3·9	4·9
Total	30·9	30·3	36·0	35·0	21·4	28·9
	'A' and 'B' Average		'A' and 'B' Average		'A' and 'B' Average	
Ingots made, tons	429,181		438,399		522,454	
Brick, lb./ton ingots						
Silica	22·4		26·5		16·5	
Firebrick	3·4		3·1		2·2	
Magnesite	0·9		1·0		2·0	
Chrome magnesite	3·8		4·4		4·4	
Total	30·5		35·0		25·1	
Type of fuel	Mixed gas		Mixed gas + pitch creosote		Cold C.O.G. + pitch creosote	

to see a roof 'burn' or 'run,' as was the case with an overheated roof on mixed-gas firing, but the roof appears to have a constant 'sweat' of silica draining to the back and front skewbacks, which results in characteristic cutting of the top of the linings. Roof wear is now very even and it is not uncommon for the roof over Nos. 2, 3, and 4 doors to be worn to a uniform 3–5 in. thickness just before the furnace comes off, with the ends of the roof still 9–10 in. thick. To maintain even roof wear and to ensure that the whole roof is worn out together, the 12-in. rings used at the ends of the furnace are covered with insulating brick to maintain a more uniform temperature from end to end of the roof. This also has the effect of giving more uniform radiation over the whole of the bath area. Details of roof life are:

1947–49 15 roofs averaged 76 days, *i.e.*, 25,740 tons/roof.
1949–51 11 roofs averaged 105 days, *i.e.*, 37,605 tons/roof.
1951–53 20 roofs averaged 72 days, *i.e.*, 30,107 tons/roof.

'A' Furnace

1947–49 6 roofs averaged 92 days, *i.e.*, 30,371 tons/roof.
1949–51 6 roofs averaged 110 days, *i.e.*, 38,279 tons/roof.
1951–53 9 roofs averaged 78·5 days, *i.e.*, 32,632 tons/roof.

'B' Furnace

1947–49 9 roofs averaged 66 days, *i.e.*, 22,652 tons/roof.
1949–51 6 roofs averaged 100 days, *i.e.*, 36,797 tons/roof.
1951–53 11 roofs averaged 66 days, *i.e.*, 28,041 tons/roof.

Table XII
FUEL VALUES, FRODINGHAM MELTING SHOP

	Fuel Value, therms/ton of ingots, from:				Rate of Supply, therms/hr.	Output, ingot tons/gross hr.*
	Pitch Creosote	Blast-Furnace Gas	Coke-Oven Gas	Total		
1947–48	...	13·9	27·6	41·5	551	13·28
1948–49	0·9	13·4	27·0	41·3	570	13·79
1949–50	3·9	12·1	24·8	40·8	610	14·96
1950–51	5·5	11·1	25·9	42·5	634	14·92
1951–52	11·6	0·1	24·7	36·4	585	16·08
1952–53	11·7	...	24·7	36·4	681	18·71
1953 to date	12·9	...	25·4	38·3	730	19·05

* Output, ingot tons/gross hr. × 168 = average actual weekly output

Table XI gives details of the refractory consumptions in periods of approximately two years since the inception of the plant.

The roof life has decreased in weeks but the output has increased from 350 tons/furnace-day to 420 tons/furnace-day and, despite a small increase in pounds of roof brick per ton of ingots, the overall refractory consumption shows a reduction.

The magnesite and chrome magnesite used has increased slightly by 1·7 lb./ton of ingots since 1947–49. The decrease of 7·1 lb. of silica and firebrick used counterbalances the more expensive basic brick.

The figures are all the more encouraging as they show reductions when compared with the plant in its first two years.

Fuel Consumptions

In the original design of the burner, the aim was to operate the furnace with 30% pitch creosote and 70% coke-oven gas. Table XII records the changing proportions of fuels since the inception of the plant in 1947.

The number of therms per hour supplied to the furnace shows a steadily increasing tendency, but the primary aim that only 30% of the heat was to be supplied from the more expensive pitch creosote has been maintained. The increased gas velocity from the burner nozzle, as shown in Table II, has materially assisted in this by enabling more gas to be efficiently burnt in the same furnace volume without undue damage to the brickwork of the roof or linings. From 1948, when the shop had settled down on straight mixed gas, to 1953, when cold-gas firing had been in use two years, the output has increased by 36·2%, the number of therms per hour has increased by 19·3%, and the number of therms per ton has decreased by 11·9%. Making allowances for an upward trend if mixed gas had continued from 1951, an increase in output of about 15% can be claimed for the conditions on this particular shop.

Acknowledgments

The author thanks the management of the Appleby-Frodingham Steel Company for permission to publish this paper, the staff of the Drawing Office, Steelworks Engineers, Engineering Research, Cost Department, and Melting Shops for the assistance they have given in the developments described, and, lastly, the operatives of the Frodingham melting shop, who have put these developments to such good use.

References

1. A. JACKSON: *J. Iron Steel Inst.*, 1949, vol. 162, pp. 136–162.
2. N. H. BACON: *Iron Steel*, 1945, vol. 18, pp. 86–90 and 124–126.
3. W. O. PHILBROOK and M. B. BEVER (ed.): "Basic Open Hearth Steelmaking": 1951, New York, A.I.M.M.E.

"OPERATION SERAPHIM"

On 29th July, 1954, at Scunthorpe, Sir Archibald Forbes, Chairman of the Iron and Steel Board, started up the new sinter plant and lit the fourth and newest of the row of blast-furnaces at the South Ironworks of the Appleby-Frodingham Steel Company. The ceremony marked the culmination of the reorganization of the ironworks begun before the Second World War. The first two of these blast-furnaces, "Queen Mary" and "Queen Bess," were put down in 1939.

The Seraphim scheme, costing £15,000,000, is the name given to the extension to the South Ironworks built since the war under the direction of Mr. I. M. Kemp, Chief Designer at Appleby-Frodingham. It includes the third and fourth of the blast-furnaces, named "Queen Anne" (blown in on 1st March, 1954) and "Queen Victoria," ancillary ore-preparation and sinter plant, with turbo-blowers and a 2,000,000-gal./hr. cooling tower. "Queen Victoria," slightly larger than "Queen Anne," is the largest blast-furnace in Europe. Its hearth diameter is 28 ft. 6 in. and its effective volume is 44,351 cu. ft. These figures compare with 27 ft. and 42,372 cu. ft., respectively, for "Queen Anne."

Reasons for the changes and development at Appleby-Frodingham were many. The most important was that the quality of the local ore, already poor, has been deteriorating (the iron content is about 21%), and if pig-iron was to continue to be produced from the local ores without making a loss, drastic alterations in plant would have to be made. The four blast-furnaces will work entirely on sinter burdens, which will enable them to work as economically as possible and produce iron of improved quality. With this improvement in the technical efficiency of ironmaking goes a reduction in the use of metallurgical coke, and thus a saving in the country's scarcest raw material, coking coal. The four furnaces replace the ten which were used before Seraphim came into operation.

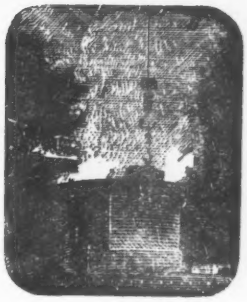
There is a shortage of suitable labour in the surrounding district, but this fact has been in part countered in the new plant by having pig-iron production concentrated in one part of the works. This naturally brings about an enormous saving in capital costs. The output per man-hour of the new plant will show a large increase on the figure obtaining before the decision to go over to 100% sinter burdens, with the considerable reduction in operating costs which this implies.

The Seraphim scheme is designed to boost the yearly output of pig-iron at Appleby-Frodingham by about 600,000 tons. The planned output for the whole plant is now about 1,400,000 tons per annum. The expected weekly output for "Queen Anne" was 6000 tons, but this figure has been exceeded, as an average of 7000 has been obtained, with a world record for lean ores of 7390 in one week shortly before the blowing-in of "Queen Victoria." This was beaten handsomely by "Queen Victoria" during the week ending 18th September, 1954, when a tonnage of 8270 was produced.

Much of the research and planning for Seraphim was carried out at a time when the future and the ownership of the iron and steel industry was in some doubt. The scheme is therefore a lasting tribute to the industry, skill, and adaptability of those whose initiative and collaboration have assured the continued and profitable working of the local ores, when it seemed a distinct possibility that this raw material, because of its poor quality, would no longer be an economic proposition in the production of pig-iron.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



High-Temperature Water Cooling of O.H. Furnaces by Steam-Producing Elements

By F. J. Feltoe, A.M.I.E.E., A.M.I.Mech.E., and P. M. Moreton, A.M.I.E.E., A.M.I.Mech.E.

SYNOPSIS

The paper outlines briefly the method of 'steam' cooling and describes some of the developments in its application to open-hearth furnace cooling in the German steel industry. A comparison is made between this method and the more conventional water-cooling systems to establish the financial advantages in terms of capital and operational costs.

This paper is not intended as a detailed analysis, but it is hoped that the subject as outlined will be sufficient to interest the U.K. steel industry in its possibilities.

The principle of using steam for cooling furnace door frames was observed in operation in 1953 at three German steelworks: Georgsmarienhütte, Osnabrück; Stahlwerke Bochum; and Westfallenhütte Dortmund. 1030

It is now standard practice to use a water-cooling system for open-hearth furnaces. The amount of cooling depends on the design of the furnace, but it is usual to supply water with an inlet temperature of 60–70° F. (15–21° C.), which acquires a temperature rise of up to 25° F. (14° C.) before leaving the furnace.

Most steelworks have to conserve water wherever possible, and a recirculating system of some kind is generally used. A typical arrangement is shown in Fig. 1. This involves a storage tank, from which the water is gravity-fed to the furnaces and thence to a hot well. The water is then pumped to the cooling tower, from which it passes to a cold well, ready to be pumped again to the storage tank. There are, of course, a number of variations of this arrangement, but it serves to illustrate the normal set-up.

Since the actual furnace-operating temperature is about 3000° F. (1650° C.), it is obvious that an increase in the working temperature of the cooling water of 300–400° F. (165–225° C.) would not affect the performance of the furnace coolers, since the relative temperature gradient is still considerable. This idea, although not new, has been put into practice at several steelworks in Germany, using a technique in which the heat normally lost in the furnace-cooling water is harnessed to produce useful work.

The circulating system is designed so that each door frame or buckstay cooler is, in effect, a small water-tube boiler of the forced-circulation type. Briefly, water at the saturation temperature, corresponding to the pressure used, is pumped from a boiler drum through the various furnace coolers, in which the latent heat of evaporation is absorbed. The resulting steam–water mixture returns to the drum, where the steam separates and passes to a superheater, whilst the water, together with whatever make-up

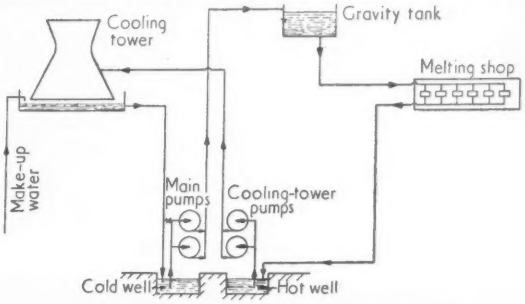


Fig. 1—Conventional cooling system

Manuscript received 12th August, 1954.

Mr. Feltoe, until recently with the Steel Company of Wales Ltd., is now with British Oil and Cake Mills Ltd., and Mr. Moreton is with McLellan and Partners.

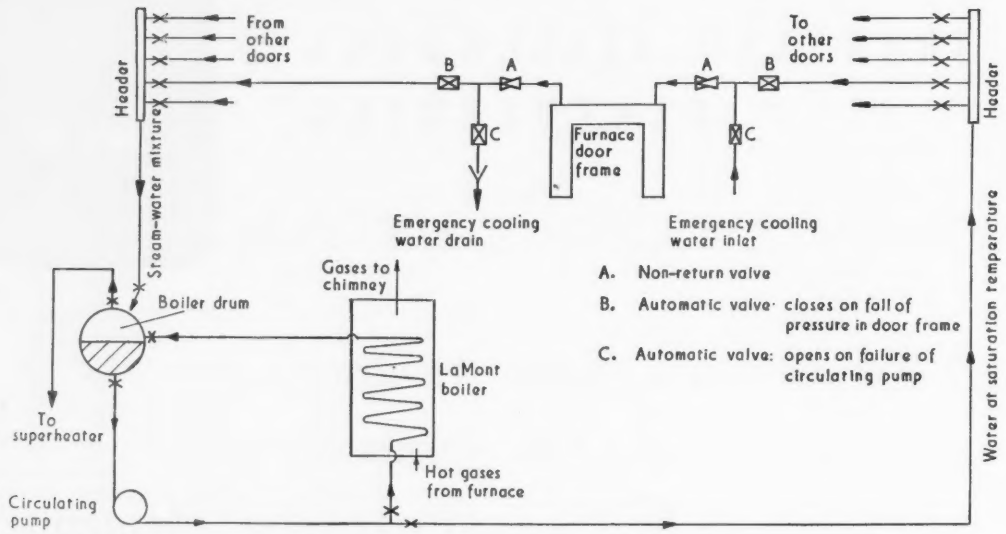


Fig. 2—Steam cooling of door frames in conjunction with La Mont waste-heat boilers

has been added, is again circulated around the coolers.

Figure 2 shows this system, when operated in conjunction with a La Mont waste-heat boiler, raising steam from the heat of the furnace flue gases. This arrangement is particularly convenient, because the special boiler drum and circulating pump do not have to be purchased solely for the furnace-cooling system. It is possible, however, to operate the door-cooling system independently or in conjunction with a fire-tube waste-heat boiler, the latter arrangement being shown in Fig. 3.

Although still in the experimental stage, plans are well advanced for installations operating at pressures up to 600 lb./sq. in., and several have operated successfully for over 12 months with pressures of about 150 lb./sq. in. In the latter case the cooling medium would be at an average temperature of 366° F. (186° C.) and in the former at 490° F. (254° C.).

As shown in Fig. 2, the system is arranged so that in emergencies the boiler drum and circulating pump can be automatically isolated, and straight-through cooling can be used. This would be necessary, for instance, if the circulating pump failed, or if pressure fell in the door frame owing to a fracture. This complication is regarded as one of the main disadvantages of the system, but in fact the high-pressure

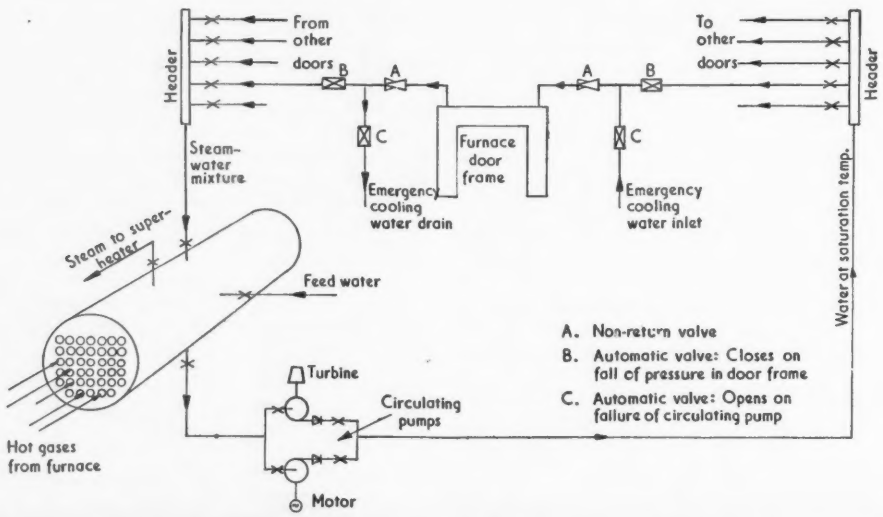


Fig. 3—Steam cooling of door frames in conjunction with conventional fire-tube waste-heat boiler

door frames are no more vulnerable to damage than the conventional type. They must, of course, be built to boiler standards and be able to withstand hard blows when the furnace is being charged.

Several types of construction are used, and these are the subjects of different patents. The frame shown in Fig. 4*a* is a seamless rolled rectangular 'tube,' divided internally by welded division plates and containing twelve small-bore tubes. Water from the circulating pump is led to the bottom of the frames, from which it rises, slowly in the main shell and rapidly in the tubes which are situated in the areas exposed to greatest heat. The lintel is similarly constructed.

Another arrangement, shown in Fig. 4*b*, is of all-welded construction and has comparatively few internal tubes, of much larger diameter. The frame in this instance is divided into halves, each of which comprises one vertical limb and half the lintel.

At present the doors themselves have to be excluded from the system because of the flexible tube which would be required to feed the door cooler and at the same time allow the unit to move. It is probable, however, that this difficulty will be overcome in time.

OPERATIONAL ADVANTAGES

This method of 'steam cooling' has three major advantages over the conventional water-cooling systems.

Increased Life of Coolers

Since treated water must be used, the quality of the water (hardness, *p*H value, etc.) can be exactly controlled, and the formation of scale on the inside of the coolers can be eliminated. Deposits of sludge can be prevented or removed by blowing the system at suitable points, thus preventing local burning of the coolers, especially in the corners. This should result in a much longer life.

If waste-heat boilers are in operation, as in the case of most modern open-hearth shops, treated water will already be available. It also becomes possible to eliminate oxygen corrosion by the use of de-aerated water, an almost impossible provision in any other scheme of cooling.

Even with the normal water-cooling system, some form of chemical treatment, such as chlorination, is often necessary, to prevent the growth of algæ (organic slime). In the case of a recirculating system

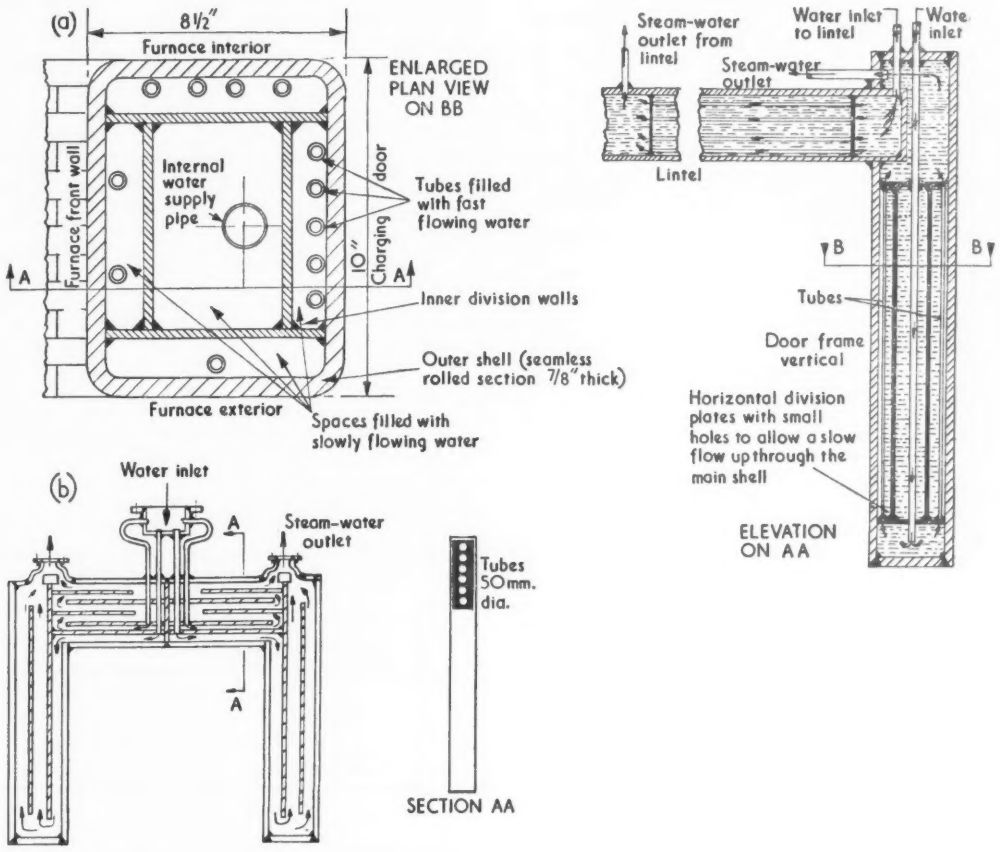


Fig. 4—Details of steam-cooled furnace door frames: (*a*) Seamless, (*b*) all-welded

using a cooling tower, up to 4% of the circulating water must be bled off and made up with fresh water to prevent concentrations.

If any serious attempt is to be made to improve the life of the normal furnace-cooler, more extensive treatment, such as the use of phosphates, to create easy-flowing sludge rather than scale, and the control of *p*H by the addition of lime, etc., becomes necessary. In view of the quantity of water flowing, such measures are expensive and generally prove uneconomical on conventional melting-shop cooling systems.

Reduction in Water Quantity

In this steam-cooling system the maximum loss of water from the circuit is equal to the evaporation plus the 'blowdown,' and, depending on the use to which the steam is put, it may even be possible to return the condensate to the system, *i.e.*, if the steam were used simply for driving the circulation pumps and for electrical generation in condensing turbines. By this means the total make-up is very much less than in a normal cooling-tower circuit, where the water to be added would be about 3–4% of the total amount circulating.

The following is a very rough comparison of water quantities for a 100-ton open-hearth (fixed) furnace:

Recirculating System Employing a Cooling Tower

Quantity circulating	30,000 gal./hr.
Evaporation losses, etc. (2%) ...	600 „ „
Bleed-off to prevent concentrations (2%)	600 „ „
Total	1200 „ „

'Steam' Cooling

Evaporation (typical for a 5-door furnace)	800 gal./hr.
Blowdown (assumed to be 10% of evaporation)	80 „ „

Table I

STEAM DATA FROM GERMAN PRACTICE

	Plant 1	Plant 2	Plant 3
Size of furnace, tons	80	30	100
Steel production, tons/hr.	6·6	2·3	8·8
No. of doors equipped with steam cooling	2	3	5
Steam pressure, lb./sq. in.	176	150	590
„ temp. (final), °F.	570	570	527
„ „ „ , °C.	299	299	275
Steam produced per door, lb./hr.	1320	1100	1750
Steam produced (all doors), lb./hr.	2640	3300	8750
Steam produced in associated waste-heat boiler, lb./hr.	5100	3200	13,200
Total steam produced, lb./hr.	7740	6500	21,950
Steam produced per ton of steel, lb.	1172	2820	2500
Heat in fuel to furnace, 10^3 B.Th.U. per ton of steel	5640	5105	5000
Heat in fuel to furnace, 10^3 B.Th.U. per ton of steel	1500	3700	3080
Percentage of furnace fuel heat recovered in steam	26·6	73	60

Total make-up required:

(*a*) No condensate recovery ...	880 gal./hr.
(*b*) 90% condensate recovery	160 „ „

Net Saving

(1) With no condensate recovery	320 gal./hr.
(2) With 90% recovery	1040 „ „

Recovered Heat

The heat normally lost is available to produce useful work. Table I (which covers three steel plants operating the system in Germany) illustrates the amounts of steam which can be raised.

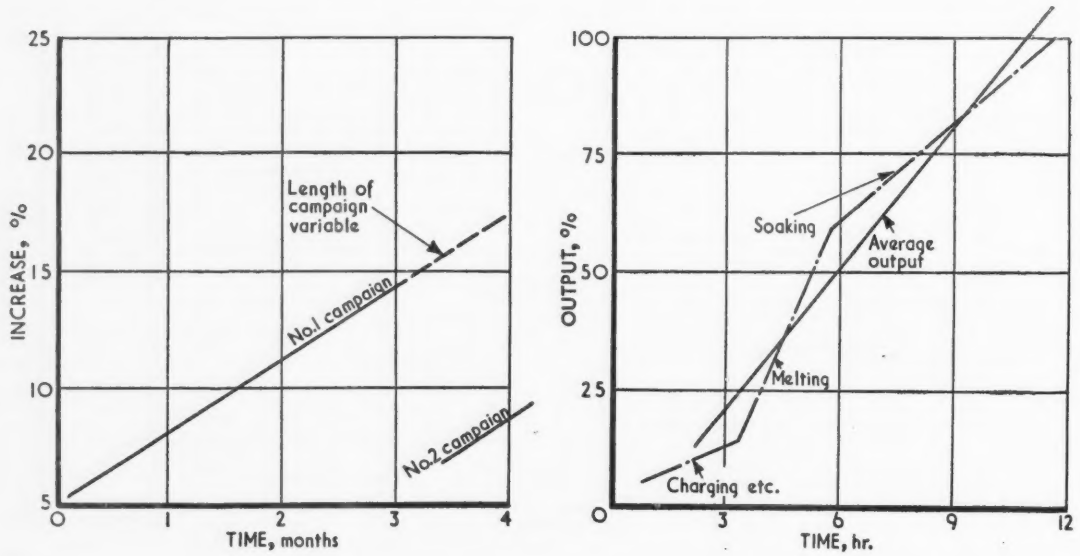


Fig. 5—Steam production in O.H. furnace door-frame coolers: (*a*) Percentage increase in rate of steam production during furnace campaign; (*b*) varying rate of steam production per heat

These figures seem remarkable, yet they are borne out by the fact that the best waste-heat boilers in the U.S.A. are recovering, as steam, up to 34% of the input heat to the furnace. This is without the assistance of steam raising in the door frames, which can confidently be expected to increase this figure by 75%.

Plant 2 is small and old, with the result that the furnace is inefficient and rejects a much larger proportion of heat to the boiler than a bigger furnace would. Plant 1 has an efficient furnace, with the result that waste-gas temperatures are low and waste-heat boiler output is therefore quite small. It can be anticipated, however, that the amounts of steam produced in furnace coolers will be largely independent of the furnace fuel efficiency (*i.e.*, unlike the output from waste-heat boilers, which drops as the furnace regenerators become efficient).

It is found in plant 1 that the steam output from the coolers alone is sufficient to run the circulating pumps and produce up to 100 kW. for other purposes. As the lining and bricks fall away from around the coolers during the campaign, the steam output increases slightly. This is shown in Fig. 5*a*.

Over the course of one heat the steam output also varies. It is least during charging and melting, when the charge is absorbing much of the heat supplied to the furnace, and greatest during the soaking period, when the whole furnace is up to temperature (*see* Fig. 5*b*).

FINANCIAL ADVANTAGES

In addition to the operational advantages, there is a certain financial saving in capital cost by installing this system:

(i) Cooling towers are unnecessary and the use of hot and cold wells and gravity tanks is avoided

(ii) Only one set of circulating pumps and one boiler drum need be used. As with La Mont waste-heat boilers, it is quite practicable to install cooling elements on several furnaces, all being served by a single set of pumps and all discharging their steam to a common drum. This results in a very cheap installation, but rather extensive pipe runs are required

On the other hand, however, the door frames will be more expensive than those used for low-pressure water. One company which operates the system stated that the steam-cooled door frames cost four times as much as the water-cooled frames, and another company quoted a price of £175 per door, exclusive of erection costs.

Maintenance costs on door frames are reduced, but this will probably be balanced by the additional maintenance on valves and pipework operating at a higher temperature and pressure.

Arrangement 1 (Fig. 2)

If La Mont waste-heat boilers are being operated, circulating pumps and boiler drums already exist and, provided that these are of sufficient capacity, the furnace coolers can simply be connected in parallel with the boiler. This leaves only coolers and pipework to be purchased. The total cost of frames, valves, and pipework to plant 3 in Table I was about £3500.

It is difficult to ascribe a value to steam produced in this way but a typical cost of producing steam in a steelworks fuel-fired boiler is 4*s*. 4*d*. per 1000 lb. of steam. In waste-heat boilers with no charge for fuel the steam production cost is about 2*s*. per 1000 lb. of steam, so that steam raised in furnace coolers represents a saving of 2*s*. 4*d*. per 1000 lb. Using this figure, and assuming that the furnace is in production for only nine months in every year, the annual value of steam produced in the door frames of plant 3 would be about £6600. The cost of the installation would be repaid in less than eight months.

These figures are rough in the extreme, but they illustrate that the installation shows a good return on its initial cost.

Arrangement 2 (Fig. 3)

Where, as is more usual, a fire-tube waste-heat boiler is in use, a circulating pump can be arranged, drawing water from the shell and discharging the steam–water emulsion from the furnace coolers back into it. This will, in addition, provide a measure of positive circulation for the waste-heat boiler and improve its performance. Using this arrangement a circulating pump must be purchased in addition to the cooling frames and pipework.

Arrangement 3

If it is decided to operate the high-temperature water-cooling system independently of any waste-heat boiler, it will be necessary to buy a boiler drum and circulating pumps, making this the most expensive of the possibilities. Even in this case, it is usual to pass the saturated steam into the shell of an existing fire-tube boiler, so that use can be made of its superheater.

Both the latter schemes will involve more capital outlay than the first, and if a conventional cooling system, with gravity tanks, etc., is already in existence, it becomes more difficult to justify the initial expense of steam cooling. In the case of a completely new installation, however, the savings, both initially and in operation, are substantial.

POSSIBLE APPLICATIONS

The application of high-temperature water cooling, with incidental production of steam, is by no means limited to open-hearth furnaces. Steel reheating furnaces, for example, usually require water cooling of the skids along which the slabs, billets, etc., are pushed, and blast-furnaces use very large quantities of water for cooling brickwork. These are both potential fields of application for steam cooling, but, of course, the introduction of new techniques such as this must on no account interfere with the prime function of these furnaces, namely, producing iron and steel.

In the steel industry the value of heat savings tends to be overshadowed by the value of the product against which such savings must always be weighed, but it is to be expected that rising fuel costs will, in the future, require more serious attention to be given, even to these comparatively untried developments.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Joint Metallurgical Societies' Meeting in Europe, 1955

An important meeting on the scientific, metallurgical, and production problems of the iron and steel and non-ferrous metals industries will be held in Europe on 1st–18th June, 1955. The meeting will be joint between the American Institute of Mining and Metallurgical Engineers, the American Society for Metals, and leading metallurgical societies in Great Britain, Germany, Belgium, and France. Its objects are to establish personal contacts between experts in the U.S.A. and in Europe, to provide opportunities for scientific and technical discussion, to enable visitors from the U.S.A. to see something of the metallurgical industries of Europe and to visit places of historical and other interest, and to foster better understanding and co-operation among all concerned.

The scope of the meeting will cover ironmaking (including coke and ore preparation); steelmaking; mechanical working and heat treatment, both ferrous and non-ferrous (including hot and cold rolling, forging, wire-drawing, and continuous casting, but not the foundry industry); refining and fabrication of non-ferrous metals; surface treatment (including finishing and coating); metallurgical education and training in industry; metallurgy and research.

His Royal Highness The Duke of Edinburgh, K.G., has graciously consented to be Patron of the Meeting in Great Britain.

Summary of Programme

The first section, in London and Great Britain (1st–7th June), will be organized by The Iron and Steel Institute and the Institute of Metals. Meetings in London from 1st to 3rd June will be followed by five tours to industrial districts: (i) South Wales, (ii) Birmingham, (iii) Sheffield, (iv) North East Coast, (v) Scotland.

The second section, in Düsseldorf, Germany (9th–12th June), will be organized by the Verein deutscher Eisenhüttenleute and the Deutsche Gesellschaft für Metallkunde, in conjunction with the Gesellschaft deutscher Metallhütten und Bergleute.

The third section will consist of a one-day visit on 13th June to Liège, Belgium, organized by the Centre National de Recherches Métallurgiques.

The fourth session, in Paris and France (14th–18th June), will be organized by the Société Française de Métallurgie.

Post-Meeting Tours

After the main meeting in Great Britain, Germany, Belgium, and France, tours will be organized to meet individual requirements in other countries, including Austria (by invitation of the Eisenhütte Oesterreich), Italy (by invitation of the Associazione Italiana di Metallurgia), Spain (by invitation of the Instituto del Hierro y del Acero), and Switzerland.

Technical Discussions

A Plenary Session will be held in each country, but most of the technical and scientific work will be conducted by means of discussion groups. The European Societies will appoint Group Leaders who are recognized authorities to guide the discussion on each subject, and will ensure that leading experts are available to take part in the discussions. A list of the subjects selected for discussion in each country will be issued later.

Participation by Members of the Institute

Visits to works and some of the social functions are by invitation, and these will be restricted. The arrangements for Members of both Institutes to take part in technical meetings will be announced later.

Travel Agents and Managers of the Meeting in Europe

Messrs. Thos. Cook and Son, Ltd., have been appointed Travel Agents and Managers of the Meeting in Europe. By arrangement with the American Joint Committee they will also handle transatlantic travel when required and be responsible for issuing the programmes.

Secretariat and Enquiries

In the U.S.A. enquiries may be directed to Thos. Cook and Son, Inc., 587 Fifth Avenue, New York, N.Y., from whom Application Forms for participation in the meeting may be obtained. In Europe, information about details of arrangements in each country is obtainable from the Secretaries of the participating societies. The Honorary General Secretary of the European Committee is Mr. K. Headlam-Morley, Secretary of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1.

NEWS OF MEMBERS

▶ Mr. W. O. Campbell Adamson, personnel superintendent of the Steel Division of the Steel Company of Wales Ltd., has been appointed Assistant General Manager to the Redbourne Section of Richard Thomas and Baldwins Ltd.

▶ Mr. C. Anderson has left Stewarts and Lloyds Ltd. to become Personal Assistant to the Managing Director of Robert Taylor and Co., Ltd. (Ironfounders).

▶ Mr. W. Barr and Mr. R. P. Towndrow have been appointed Directors of Colvilles Ltd., and Mr. Towndrow has assumed special responsibilities in connection with the Company's new plant at Ravenscraig. Mr. R. Marshall and Mr. S. Thomson have been appointed Directors of the Etna Iron and Steel Co., which recently transferred to Colvilles Ltd.

▶ Mr. B. Edmondson has left the Department of Metallurgy of the University of Birmingham, and has joined the Metallurgy Division of the National Physical Laboratory.

▶ Mr. H. K. FARMERY has left the Department of Metallurgy of the University of Cambridge to join the Fulmer Research Institute, Stoke Poges.
▶ Mr. P. D. GASKELL has left Kings College, University of Durham, and is at present serving with the R.A.F.
▶ Mr. T. E. GREEN has completed three years' commissioned service with the R.A.F. and has taken up an appointment as Development Metallurgist with the Plessey Co., Ltd., at Towcester.
▶ Mr. W. E. HOARE has been awarded the degree of D.Sc.
▶ Mr. C. P. KERR has taken up an appointment in the Inspectorate of Armaments (Metals Division) of the Ministry of Supply.
▶ Mr. W. E. J. LEWIS has retired from his appointment as Principal Surveyor for Metals to Lloyd's Register of Shipping.
▶ Mr. E. MORGAN has been appointed General Manager in charge of Research to the Stanton Ironworks Co., Ltd.
▶ Mr. J. B. Moss has taken up a lecturing post in the Department of Chemistry and Metallurgy, Wandsworth Technical College.
▶ Mr. E. G. V. NEWMAN has been made a F.R.I.C.
▶ Dr. L. NORTHCOTT has been appointed Senior Superintendent in the Armament Research Establishment, Ministry of Supply.
▶ Mr. A. E. NYGREN has left Munkfors Bruk, Uddeholm, to join Sandvikens Jernverk, Sandviken, Sweden.
▶ Dr. N. H. POLAKOWSKI has left La Salle Steel Co., Chicago, to join the Department of Metallurgical Engineering, Illinois Institute of Technology.
▶ Mr. A. STIRLING has been appointed Assistant to the Managing Director of Iron and Steel Production, Stewarts and Lloyds Ltd.
▶ Mr. J. F. WATKINSON has left Sheffield University and has joined the Fighting Vehicles Design Department of the Ministry of Supply at Chertsey.
▶ Mrs. M. WEDDLE has been awarded the degree of M.Sc.
▶ Mr. D. H. WILLEY has left the B.S.A. Co., Ltd., to join Henry Wiggin and Co., Ltd.

Obituary

Mr. GEORGE BAKER, O.B.E., Managing Director and Chairman of Woodhouse and Rixson Ltd., Sheffield, in September, 1954. He had been a Member since 1902.

Mr. C. NOWELL, Chief Librarian, Central Library, Manchester, on 9th August, 1954.

CONTRIBUTORS TO THE JOURNAL

R. H. Hickley, B.Sc., Ph.D.—Research Metallurgist in the Development and Research Department of the Mond Nickel Co., Ltd., Birmingham.

Dr. Hickley was born in 1927 and was educated at Thornes House School, Wakefield, and at the University of Sheffield, graduating with Honours in Metallurgy in 1948. He remained at the University to carry out work on steel graphitization, and was awarded the degree of Ph.D. and a Brunton Medal in 1952. He took up his present appointment in the same year.

A. G. Quarrell, D.Sc., F.Inst.P., F.I.M.—Head of the Metallurgy Department and Dean of the Faculty of Metallurgy at the University of Sheffield.

Professor Quarrell was born in 1910. He received his scientific education at the Imperial College of Science and Technology, graduating with Honours in Physics in 1932. He spent five years at Imperial College working with Professor G. I. Finch on the development and application of electron diffraction, until in 1936 he became research assistant to Professor J. H. Andrew in the Metallurgy Department of the University of Sheffield.

A. G. Quarrell

R. H. Hickley

In the following year he was appointed assistant lecturer and in 1940 lecturer in Metallurgy. In 1945 he took up the post of senior metallurgist to the British Non-Ferrous Metals Research Association, and six months later was appointed research manager. He returned to the University of Sheffield in 1950 as Professor of Physical Metallurgy, with responsibility for the new post-graduate school in that subject.

A Member of Council of the Institution of Metallurgists, Professor Quarrell is also a member of the Inter-Services Metallurgical Research Council, Chairman of its Non-Ferrous Committee, and a member of its Ferrous Committee. He is an Honorary Consultant to the Atomic Energy Research Establishment and serves on one of the Committees of the Scientific Advisory Council. He represents The Iron and Steel Institute on the Council of the British Iron and Steel Research Association.

W. Jackson, A.I.M.—Melting-Shop Manager, Appleby-Frodingham Steel Co.

Mr. Jackson was born in 1914 and was educated at Brigg Grammar School, and later at the Scunthorpe Evening Technical School, where in 1932 he was awarded First Prize in the City and Guilds examination in iron and steel manufacture. He joined the United Steel Companies, Ltd., as a technical apprentice in 1931; four years later he was appointed Assistant Melting-Shop Manager at the Appleby-Frodingham Steel Co. He took up his present appointment in 1952.

IRON AND STEEL ENGINEERS GROUP

The **Twenty-Seventh Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Thursday, 9th December, 1954.** A Buffet Luncheon will be held in the Library.

The following is the detailed programme:

10.30 A.M.–12.45 P.M.—Presentation and discussion of: "*Practical Aspects of the Cold Rolling of Narrow Steel Strip*," by T. W. Hood (Samuel Fox and Co., Ltd.)

12.45–2.0 P.M.—Buffet Luncheon (tickets 4*s.* 6*d.*)

2.0–4.0 P.M.—Presentation and discussion of: "*Wire Drawing and Wire-Drawing Machinery*," by H. Richards (Marshall Richards Machine Co., Ltd.).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Forty-Third Steelmaking Conference

The 43rd Steelmaking Conference was held at Ashorne Hill, Leamington Spa, on 29th–30th September, 1954. Dr. T. P. Colclough, C.B.E., Chairman of the Steelmaking Divisional Panel, was Chairman, and Mr. R. Lamb, Chairman of the Ingots Committee, acted as Vice-Chairman. The Conference opened with the subject of

longitudinal panel cracking in plain carbon and alloy steel ingots, and the discussion was introduced by brief accounts of examples of the occurrence of this defect at five works given by Mr. F. R. Middleton, Mr. R. Wilcock, Mr. F. B. Pickering, Mr. B. L. Biggs, and Mr. W. H. Glaisher. These examples were very varied in nature, and the information presented, together with suggestions put forward during discussion, indicated promising new lines of research.

A series of films on the continuous casting of steel provided the basis for the discussion on the second day of the Conference. The films dealt with development work carried out at the B.I.S.R.A. Laboratories at Battersea and Sheffield. Two papers, one on the practical application of the process, and the other on the problem of rupture in continuous casting, were presented by Mr. M. P. Newby and Mr. J. Savage respectively, and the ensuing discussion on the subject proved very lively.

Steel Users' Section

In accordance with the steel industry's policy to promote the efficient use of steel, the giving of help and advice to enquirers from the many and various users of steel has long been an important part of the activities of the Association, and many firms using steel are already Associate Members of B.I.S.R.A. They and other users have problems in the specification of steels for particular purposes, metallurgical treatment, equipment for metal working, prevention of corrosion, etc.

The establishment of laboratories in Sheffield has made possible the setting up of a 'Steel Users' Section' as a counterpart to the recently announced Corrosion Advice Bureau at the Battersea Laboratories. This new section is under the supervision of Mr. C. N. Kington, Group Manager of the B.I.S.R.A. Laboratories in Sheffield and Research Superintendent of the Cutlery Research Council. The staff of the Section at present consists of a metallurgist and an engineer who are well experienced in user problems. They will have the help of other staff of the laboratories as necessary.

As in the past, this Section will, for each particular problem, work in close collaboration with the maker of the steel. Much of the advice will be provided free but charges depending on the extent of the investigation required and on the relationship of the enquirer to B.I.S.R.A. will be made in some cases. The Section will also help to organize technical research for groups of user firms having common interests.

Enquiries should be made either to B.I.S.R.A. Headquarters at 11 Park Lane, London, W.1, or directly to the Sheffield Laboratories, Hoyle Street, Sheffield, 3.

AFFILIATED LOCAL SOCIETIES

Sheffield Society of Engineers and Metallurgists

A joint meeting between the Sheffield Society of Engineers and Metallurgists and the Engineers Group of the Institute will be held on 13th December, 1954, when Mr. W. Udall will present a paper on "*The Park Gate 11-in. Continuous Bar Mill.*" The meeting will be held in the University Buildings, St. George's Square, Sheffield, 1, commencing at 7.30 P.M.

NEWS OF SCIENCE AND INDUSTRY

Research Fellowship

Applications are invited for the T.I. Research Fellowship tenable in the Department of Metallurgy of the University of Sheffield. The object of the Fellowship is to advance knowledge in the field of Metallurgy; candidates should already have some research experience, but not necessarily in this field. Normal tenure will be five years, but the appointment will be for two years in the first instance and thereafter will be renewable annually. The stipend is £750 per annum for the first year, rising by annual increments of £50 to £950 per annum, together with superannuation provision under the F.S.S.U. A higher stipend may be paid to an exceptional candidate. Applications (3 copies) including the names and addresses of referees and, if desired, copies of testimonials, should reach the Registrar (from whom further particulars may be obtained) not later than 15th December, 1954.

Chair of Physical Metallurgy at Sheffield

Applications are invited for the Chair of Physical Metallurgy at the University of Sheffield, to be filled early in 1955. The successful candidate will be required to be mainly responsible for the Postgraduate School in Physical Metallurgy and also to take some part in the work of the Metallurgy Department. The salary will be not less than £2000 p.a. with F.S.S.U. provision and family allowance. Applications (20 copies), which should include the names and addresses of referees and, if desired, copies of testimonials, should be sent to the Registrar (from whom further particulars may be obtained) by not later than 8th January, 1955.

New Electric-Arc Furnace

A new electric-arc furnace, the largest in Western Europe, was put into operation at the Stocksbridge Works of Samuel Fox and Co., Ltd., on 3rd November, 1954. When the furnace is in full operation it will have a weekly power consumption of 1 million units, and the furnace transformer weighs over 70 tons.

The furnace has an inside dia. of 19 ft., backed with an 18-in. thick refractory lining, and the roof, which is 14 in. thick, weighs 30 tons. Charging is carried out by lifting the roof hydraulically and swinging it clear of the body. The charge of scrap is then lifted over the furnace by a crane and discharged by means of a charging basket directly into the furnace. In this way 60 tons of scrap metal can be charged into the furnace in two lifts in a few minutes. Heat is generated inside the furnace by arcing between the ends of three 20-in. dia. electrodes and the metal charge. The furnace is tapped by tilting it forward hydraulically.

X-Ray Beam Centring Attachment

A new device designed to obtain a high degree of accuracy in centring an X-ray beam has been manufactured by Solus-Schall Ltd. It is in the form of a mains-operated attachment which slides on to the window of the X-ray tube shield and is held in place by spring-loaded clips. A strong beam of light passing through a lens projects the shadow of a cross on to the object to be radiographed, the centre of the cross marking the centre of the X-ray beam.

Silicon Carbide Furnace Element

A new silicon carbide furnace element known as 'Crusilite' has recently been produced by the Morgan Crucible Co., Ltd. The element, which is in the form of a tube with a spiral of the requisite length as the central hot zone, is suitable for working at element temperatures ranging from 800° C. to 1575° C.

New Company in Switzerland

Electric Furnace Co., Ltd., have recently formed a new subsidiary company in Switzerland. The company is named EFCO Industrieofen A.G., with the alternative French and English titles EFCO Fours Industriels S.A.

and EFCO Industrial Furnaces Ltd. The Administrative Board consists of W. Schubarth (President), J. A. Monks, and G. Schoeffter, and the registered office will be in Basel, Switzerland. The Company will supply electric furnace equipment for all types of industrial heat-treatment, and also heat-treatment salts and compounds.

CORRIGENDUM

Discussion on Structure of Cast Irons

In the report of the discussion on the structure of cast irons at the Annual General Meeting, published in the October issue of the *Journal*, reference was made on p. 153 to "Dr. Hadfield" and on p. 154 to "W. H. Hadfield." In each case, of course, the name should have read "Hatfield."

DIARY

2nd Dec.—EBBW VALE METALLURGICAL SOCIETY—"*The Effects of Some Metallurgical Factors on the Development of Hydrogen Swells in Cans Made from Electrolytic Tinplate*," by E. Morgan—Lecture Hall, Richard Thomas and Baldwins, Ebbw Vale, 7.15 P.M.

3rd Dec.—INSTITUTION OF MECHANICAL ENGINEERS—"*The Roll-Setting Method of Automatic Control of Gauge in Hot and Cold Rolling Mills*," by R. B. Sims and K. H. Slack—1 Birdcage Walk, Westminster, London, S.W.1, 5.30 P.M.

3rd–12th Dec.—3rd Salon de la Chimie et des Matières Plastiques—Porte de Versailles, Paris.

4th Dec.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Fuel and the Future*," by W. I. Jones.

6th Dec.—INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield and District Branch)—Discussion on "*Methods of Making a Typical Casting in Cast Iron*"—College of Technology, Pond Street, Sheffield, 7.15 P.M.

6th Dec.—CLEVELAND INSTITUTION OF ENGINEERS—"*The Design and Construction of Lackenby Steelworks*," by A. P. Clark and S. Cornforth—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

7th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"*The Determination of Nitrogen in Steel*," by J. D. Hobson—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

8th Dec.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Acid Burdening of Blast Furnaces*," by J. Colvin—Nottingham and District Technical College, Shakespeare Street, Nottingham, 7.30 P.M.

8th Dec.—NORTH WALES METALLURGICAL SOCIETY—Question Night—County Primary School, Plymouth Street, Shotton, Chester, 7.15 P.M.

8th Dec.—MANCHESTER METALLURGICAL SOCIETY—Discussion on Mechanical Testing—Lecture Room, Central Library, Manchester, 6.30 P.M.

9th Dec.—IRON AND STEEL ENGINEERS GROUP—Twenty-Seventh Meeting—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

13th Dec.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—"*Some Advantages of the Use of Oxygen in Fixed Open Hearth Furnaces*," by A. S. Barker—North Lindsey Technical College, Kingsway, Scunthorpe, 7.30 P.M.

13th Dec.—INSTITUTE OF METALS (Sheffield Local Section) (Joint meeting with the Engineers Group and the Sheffield Society of Engineers and Metallurgists)—"*The Park Gate 11-in. Continuous Bar Mill*," by W. Udall—University Buildings, St. George's Square, Sheffield, 7.30 P.M.

16th Dec.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Presidential Address: "*The Manufacture and Properties of Hollow Forgings*," by K. G. Lewis—Star and Garter Royal Hotel, Wolverhampton, 7.30 P.M.

16th Dec.—LIVERPOOL METALLURGICAL SOCIETY—"*Protective Atmospheres for the Heat-Treatment of Steels*," by I. Jenkins—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7.0 P.M.

16th Dec.—INSTITUTE OF METALS (London Local Section)—"*Melting and Casting under Reduced Pressure*," by H. H. Scholefield—4 Grosvenor Gardens, London, S.W.1, 6.30 P.M.

17th Dec.—NORTH EAST METALLURGICAL SOCIETY—"*Some Aspects of Iron Production*," by P. K. Gledhill—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.15 P.M.

17th Dec.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Non-Destructive Testing of Metals*," by J. M. Mowat—39 Elmbank Crescent, Glasgow, 6.45 P.M.

17th Dec.—INSTITUTION OF MECHANICAL ENGINEERS—Thomas Hawksley Lecture: "*Recent Studies of Metallic Friction*," by F. P. Bowden—1 Birdcage Walk, Westminster, London, S.W.1, 5.30 P.M.

31st Dec.—INSTITUTION OF MECHANICAL ENGINEERS—"*Development of the Lost-Wax Process of Precision Casting*," by J. S. Turnbull—1 Birdcage Walk, Westminster, London, S.W.1, 5.30 P.M.

3rd Jan.—INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield and District Branch)—Film on "*Britain's Largest Steel Casting*"—College of Technology, Pond Street, Sheffield, 7.15 P.M.

4th Jan.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*The Corrosion of Metals*," by U. R. Evans.

4th Jan.—INSTITUTE OF METALS (Oxford Local Section)—"*Titanium*," by P. L. Teed—Cadena Café, Cornmarket Street, Oxford, 7.0 P.M.

4th Jan.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Instrumentation in the Making and Processing of Steel*," by S. S. Carlisle.

5th Jan.—INSTITUTE OF METALS (South Wales Local Section)—"*Oxidation of Metals*," by U. R. Evans—Metallurgy Department, University College, Singleton Park, Swansea, 6.45 P.M.

6th Jan.—INSTITUTE OF METALS (Birmingham Local Section)—Debate—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the November, 1954, issue of the *Journal*, p. 310).

TRANSLATIONS AVAILABLE

No. 494 (Swedish). B. THYBERG: "Hot-Blast Cupolas." (*Gjuteriet*, 1954, vol. 44, Feb., pp. 19–28).

No. 495 (Polish). G. KNIAGININ: "Influence of Steel Casting Design on Internal Stress." (*Przeglad Odlewnictwa*, 1953, vol. 3, No. 12, pp. 341–346).

TRANSLATION IN COURSE OF PREPARATION

(German). H. KOSMIDER, H. NEUHAUS, and H. KRATZENSTEIN: "The Waste-Gas Conditions in the Basic Bessemer Plant When Using Various Refining Gases." (*Stahl und Eisen*, 1954, vol. 74, Aug. 12, pp. 1045–1053).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUESTS—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
Mineral Resources	400
Ores—Mining and Treatment	400
Fuel—Preparation, Properties, and Uses	401
Refractory Materials	401
Blast-Furnace Practice and Production of Pig Iron	401
Treatment and Use of Slags	402
Direct Processes	402
Production of Steel	402
Foundry Practice	403
Heat-Treatment and Heat-Treatment Furnaces	406
Forging, Stamping, Drawing, and Pressing	407
Rolling-Mill Practice	408
Machinery for Iron and Steel Plant	408
Protective Coatings	408
Powder Metallurgy	409
Properties and Tests	409
Metallography	413
Analysis	414
Economics and Statistics	414
Miscellaneous	415
Book Notices	415
New Publications	416

MINERAL RESOURCES

Britain's Iron Ore Resources. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, Oct., 1–8). The part which the iron ores of Great Britain play in the economy of pig-iron production is discussed with special reference to the expansion of nearly 50% in iron production which is envisaged by the industry's development plans. The economies, both local and national, achieved by sintering are pointed out.—R. A. R.

The Austrian Magnesites as Members of the Alpine Mineralization. W. Petrascheck. (*Berg. Hüttenmänn-Monatsh.*, 1953, **98**, Oct., 207–211). The mineralogy, structure, tectonic relationships and paragenesis of Austrian magnesite deposits are outlined. It is shown that they resemble the alpine siderite deposits in all these respects and should therefore be regarded as part of the general alpine mineralization.—E. C.

ORES—MINING AND TREATMENT

Stress Concentration Problems in Hollow Drill Steel. W. H. McCormick and H. J. Benecki. (*Min. Eng.*, 1954, **6**, Mar., 282–283). Drilling stresses are very liable to produce fatigue failure. Longer life of drill rods can result from attention to the correct design of bits and shanks, proper pinning and fitting, prevention of scaling in alloy rods, prestressing to an appropriate degree, and the avoidance of points of excessive stress concentration.—K. E. J.

Beckermet Mine. (*Mine Quarry Eng.*, 1954, **20**, Apr., 148–158; May, 205–214). The surveying, geology, development, layout, equipment and working of this West Cumberland underground hematite mine is described with illustrations.

Turkish Refractory Materials. J. Hunt. (*Refract. J.*, 1954, **30**, Mar., 92–94). The difficulties of mining and marketing Turkish chrome ore are described.—D. L. C. P.

Development of Quebec-Labrador Iron Ore Deposits; Transportation is Major Factor. W. H. Durrell. (*Min. Eng.*, 1954, **6**, Apr., 387–390). After outlining the extent and the exploration of the deposits, the author points out the importance of transportation schemes for the development of the area and moving the ore. Of interest are the 360-mile railway from Knob Lake to Seven Islands, handling stations, two projected power stations, and the St. Lawrence seaway. Ore is expected to be despatched in the late summer of 1954.—K. E. J.

Error Incurred in Sampling a Load of Ore. P. Gy. (*Rev. Ind. Min.*, 1954, **35**, Apr., 311–345). The causes of differences between the properties of the ore and a sample from it are analysed. The scatter follows the normal Gaussian curve of error provided systematic errors are eliminated. The author stresses the two fundamental conditions for correct sampling *i.e.*, (*a*) impartial selection and (*b*) accessibility of the whole initial material.—A. G.

Iron Ore Beneficiation. F. D. DeVaney. (*Eng. Min. J.*, 1954, **155**, Feb., 123–125). During 1953 the Oliver Iron Mining Co. commissioned a large pilot plant to treat magnetic taconite, and the Erie Mining Co. announced plans to build a plant to treat 88,000 long tons per day. Developments in equipment included the trends towards spiral classifiers for washing, cyclone separators using magnetite and specially designed jigs for the $-\frac{1}{4}$ in. down to + 80 mesh wash product, magnetic separators, and cyclones for use as sizing devices.—K. E. J.

Developments in Minerals Beneficiation. D. W. Scott. (*Min. Eng.*, 1954, **6**, Feb., 166–173). This is a review of developments during 1953 in ferrous and non-ferrous mineral beneficiation, with some observations on the need for increased fundamental research. Emphasis in ferrous sintering was on the control and instrumentation of operating variables, the use of very fine materials in the burden, sintering of pelletized ores, and the use of high-sinter burdens in the blast-furnace.

The Development of a Magnetic Roller-Type Filter. W. A. Colburn. (*Mines Mag.*, 1954, **44**, Jan., 29–33). The Dings filter is designed to dewater concentrates from magnetic taconites. It combines gravity and magnetic settling with the pressing action of two drums. A cake with a moisture content of 10% or less is produced from a slurry of 50% magnetite, all — 200 mesh, and the need for vacuum or compressed air equipment is eliminated.—K. E. J.

A Physical Explanation of the Empirical Laws of Comminution. D. R. Walker and M. C. Shaw. (*Min. Eng.*, 1954, **6**, Mar., 313–320). The laws of Kick and Rittinger are explained in terms of particle size, comminution being considered as basically similar to metal grinding. Mineral crushing can be studied by machine grinding operations, and evidence exists for plastic flow phenomena in comminution.—K. E. J.

Solid State Bonding in Iron Ore Pellets. S. R. B. Cooke and R. E. Brandt. (*Min. Eng.*, 1954, **6**, Apr., 411–415). Bonding, which increased with temperature and time, occurred between magnetite cubes fired at 500° C. or above, and between magnetite and hematite at 600° C. It depended on oxidation, and the formation of hematite at the lower temperatures. No quantitative strength measurements were made, but a tensile method was developed which gives data comparable with those from compression tests on pellets.—K. E. J.

Concentration of Blast-Furnace Flue Dust by Magnetizing Roasting and Low Intensity Magnetic Separation. Coche. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (12), 1909–1914). The work of the ore department of IRSID, during the spring and summer of 1952, is reported.—A. G.

FUEL—PREPARATION, PROPERTIES, AND USES

The Magnitude of the External Surface Area of Coke and an Index of Its Columnar Shape. W. Tietze. (*Stahl u. Eisen*, 1954, **74**, May 6, 618–620). The external surface area of a piece of coke may be determined by hanging it in an illuminated white 'integrating' sphere and noting the reduction in output of the indicating photocell as compared with that obtained when the coke is not present. In order to maintain a uniform light absorptivity, the coke is coated with blackboard paint and its total surface area determined by reference to calibration readings taken on similarly painted wooden pieces. The extent to which the coke deviates from cubic shape towards columnar is assessed by a coefficient obtained by dividing its area by that of a cube of the same volume. As the coke becomes more columnar, its coefficient increases from unity.—J. P.

The Use of Coke in Boilers. R. A. Mott. (*Yearbook Coke Oven Man. Assoc.*, 1954, 200–226).

A Method of Testing the Strength of Blast-Furnace Coke. W. Wolf. (*Iron Steel Inst., Translations Miscellaneous Series No.* 215, June, 1954). This is a translation of a paper which appeared in Stahl u. Eisen, 1928, **48**, Jan. 12, 33–38, *see J. Iron Steel Inst.*, 1928, **118**, 283).

Fluidization in Beds of Coal and Coke Particles: Some Effects of Size of Particles and Viscosity, Density and Velocity of Gas. L. J. Jolley and J. E. Stantan. (*J. Appl. Chem.*, 1952, **2**, Suppl. Issue 1, s62–s68). Experiments in glass tubes up to 3 in. in dia. have been carried out to examine the factors which determine the state of fluidization of beds of coal and coke particles and gas velocities required to fluidize particles of various sizes. This information is valuable when designing apparatus for gasifying coal and coke in fluidized beds. The linear gas velocity required is inversely proportional to the absolute velocity of the gas and is independent of its density; it is proportional to a power of the particle diameter which is approx. 2 for particles 0·01–0·03 in. in dia. and decreases towards unity for larger sizes.—R. A. R.

Producer Gas. G. O. Bass and G. Milner. (*Yearbook Coke Oven Man. Assoc.*, 1954, 294–333). A review of the historical development of producer gas is followed by a discussion of the factors influencing gas producer operations. The types of fuel used are tabulated, and detailed descriptions are given of wet-base and dry-base producers.—J. E. J.

REFRACTORY MATERIALS

The Cambro-Ordovician Limestone and Dolomites of the Ord and Torran Areas, Skye and the Kishorn Area, Ross-shire. H. E. Wilson. (*D.S.I.R., Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain*, 1954, **36**).

Thermal Strains During Firing of a Ceramic Body. S. P. Mitoff and J. A. Pask. (*J. Amer. Ceram. Soc.*, 1954, **37**, Apr., 168–172). An attempt is made to relate the cracking tendency during firing of an experimental ceramic body, to the thermal gradient, thermal expansion, and maximum strain in the body. This is used to illustrate a method of establishing the best firing schedule.—D. L. C. P.

Steelworks Tar. De Miscault. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (10), 1591–1593). Tar acts as a cold binder and a hot agglomerator of dolomite linings and should have a low visibility to ensure adequate wetting of dolomite grains. To maintain uniform properties of linings the tar must be stored below 80° C. in sealed vessels fitted with safety valves and brought to temperature just before use.—A. G.

Oxidation Resistances of Ternary Mixtures of the Carbides of Titanium, Silicon, and Boron. O. E. Accountius, H. H. Sisler, T. S. Shevlin, and G. A. Bole. (*J. Amer. Ceram. Soc.*, 1954, **37**, Apr., 173–177). The apparent porosity, density, and oxidation resistance at 2000° F. were measured for sintered and hot pressed mixtures of the three carbides. Superior oxidation resistances were found with compacts made from B_4C 10%, TiC 50–70%, remainder SiC.—D. L. C. P.

Viscosity Studies of System CaO–MgO–Al_2O_3–SiO_2: IV, 60 and 65% SiO_2 (Variation of Viscosity When CaO, MgO and/or Al_2O_3 are constant). J. S. Machin and T. B. Yee. (*J. Amer. Ceram. Soc.*, 1954, **37**, Apr., 177–186). Included are diagrams of the systems of isokoms at temperature intervals, on planes parallel to the zero alumina, zero lime, and zero magnesia forces of the tetrahedron, the apices of which represent 100% of each of the four oxides that make up the system.—D. L. C. P.

Solid Solution and Chromium Oxide Loss in Part of the System MgO–Al_2O_3–Cr_2O_3–SiO_2. I. Warshaw and M. L. Keith. (*J. Amer. Ceram. Soc.*, 1954, **37**, Apr., 161–168). Preliminary studies in part of the system were made by thermal and X-ray investigation, and details are given. Loss of chromium oxide by volatilization was also studied, and the effect on this of several variables is considered.—D. L. C. P.

Refractories and the Furnace Builder. E. Hošek. (*Hutnik*, (Prague), 1954, **4**, (4), 113–115). [In Czech]. The physical and thermal properties of the principal types of refractory used in the metallurgical industry are given, and the correct choice of type and dimensions of bricks for furnace construction are discussed, with special reference to open-hearth furnace walls and roof.—P. F.

Carbon as a Refractory. T. J. Wilde, M. R. Hatfield, and V. J. Nolan. (*Trans. Amer. Found. Soc.*, 1953, **61**, 640–642). The use of carbon as a refractory, particularly in the cupola, is briefly discussed.—B. C. W.

Refractory Products and Insulators. Y. Letort. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1952, "*Les Cahiers du CESSID*" *No.* III). A comprehensive account of French refractory practice is given. The preparation, properties and testing of alumina, silica, magnesite, dolomite and chrome-magnesite refractory and insulating bricks are discussed in detail. The conditions of service and types of refractory brick used in blast-furnaces, Cowper stoves, converters, mixers, basic open-hearth furnaces, arc furnaces, H.F. induction furnaces, cupolas and soaking pits are reviewed. (91 references).—B. G. B.

Study of Refractory Products and Insulators. L. Halm. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1952, "*Les Cahiers du CESSID*" No. III). Methods used to test refractory products and insulators are described; they include the resistance to heat, softening under load at high temperatures, mechanical strength, resistance to thermal shock and chemical attack. The influence of the physical properties, including density, porosity, permeability, reversible expansion aud thermal conductivity on the behaviour of refractory products is considered. The structure of refractory bricks is reviewed with the aid of a number of photomicrographs of typical structures. Methods used to test insulating materials are also considered.—B. G. B.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Bricklaying As a Factor in the Performance of Blast-Furnace Linings. W. S. Debenham. (*Iron Steel Eng.*, 1954, **31**, Mar., 76–79). The author discusses brick quality, brick shapes, the proper alignment of the lining, packing between stack lining and shell, bosh and stack cooler arches, and bricklaying techniques, and concludes that the most important element in a furnace lining is skillful bricklaying.—M. D. J. B.

The Preparation of High-Purity Iron Ingots. G. W. P. Rengstorff and H. B. Goodwin. (*Amer. Iron Steel Inst. Regional Tech. Meetings*, 1953, 353–359). The authors discuss the method used at the Battelle Memorial Institute for the production of high-purity iron. The method involves the purification of electrolytic iron flakes with hydrogen, followed by arc-melting of the purified iron into ingots. Analyses are compared with those of high-purity iron from other sources.—G. F.

Corrigendum

In the first abstract on p. 223 of the February, 1954, issue of the *Journal*, the name of the author of the paper entitled "Investigation to Determine the Reducibility of Iron Ore" should read C. Rekar.

Making of the Low Phosphorus Pig Iron with Heroult's Electric Furnace. S. Oishi. (*Tetsu to Hagane*, 1951, **37**, Apr., 194–202). [In Japanese]. The acid open-hearth process for high-grade carbon steel requires low-phosphorus pig. It can be made from steel scrap in the electric furnace; the cost is low but process control is difficult. Carbon addition is very important, but sulphur has little effect. Control of phosphorus is in accordance with Schenk's observations on slag control.—K. E. J.

The Electric Pig Iron Furnace—Possibilities and Limitations of its Use in the Iron Industry. A. Ballon. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L. 48). [In English]. The development of electric furnaces for smelting iron is outlined. The material and heat balances, power requirements, and the applicability of electric furnaces under South American conditions are discussed.—V. G.

Electric Smelting of Pig Iron. M. Ø.Sem. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.49). [In English]. The output of existing electric furnaces, and the possibilities of power economies by burden preparation and the utilization of gas produced in the furnace are discussed. The advantages of the rotating hearth furnace are outlined.—V. G.

The Sulphur Distribution Reaction between Blast-Furnace Slag and Metal. J. Taylor and J. J. Stobo. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 360–367). [This issue].

Use of Phosphorus Ores for the Production of Pig Iron for Transforming into Steel by the Thomas Process. (Basic Bessemer). Societá Ilva (Bagnoli, Italy). (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.54). [In English]. The operation of blast-furnaces in conjunction with basic-Bessemer converters and rolling mills by the Societá Ivla, Bagnoli, Italy, is briefly outlined. The burden consists of local limonitic-sideritic ores with the addition of phosphorites to produce pig containing 1·8 to 2% of phosphorus.—V. G.

Progress in the Manufacture of Pig Iron and Ferro-Alloys with the Low Shaft Electric Furnace. H. Walde. *United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.37). [In English]. The advantages of the electric low-shaft furnace for the production of pig iron and ferro-alloys are discussed.—V. G.

Methods Other than the Use of the Blast Furnace for the Reduction of Ores: The Low Shaft Furnace. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.79). [In French]. The structure is given of the international committee set up to investigate the advantages of the low-shaft furnace especially when blown with oxygen. The present state of the project and the future programme are described. Preliminary results on the reduction of fine ores and slimes agglomerated in a hot-blast cupola are appended.—A. G.

Experimental Smelting of Char-Ore Agglomerates in a Low-Shaft Blast Furnace. H. Kay and E. Gorin. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn. Coke Oven Raw Mat. Comm.*, 1953, **12**, 123–145). An agglomerate of coal and fine ore was successfully smelted in a closed-top foundry cupola with a 3 ft. hearth. Enrichment of the blast up to 25% oxygen was used in the absence of air preheating. The smelting rate based on a square foot of hearth area approached commercial blast-furnace practice. The main factor limiting the smelting capacity was the rate at which air could be blown through the burden without lifting or hanging. The weights and analyses of slag and metal, and the gas composition are given.—B. G. B.

Problems of Pig-Iron Production in the Low-Shaft Furnace. K. Säuberlich and R. Baake. (*Met. u. Giesserei Techn.*, 1954, **4**, Feb., 55–60). An experimental furnace was put into operation at the Eisenwerke West at Calbe in 1950 and nine low-shaft furnaces are now in use. The Calbe furnace produces 61 tons of pig iron daily, although the burden yield is only 18·8%. Coke consumption per ton of pig iron is 2·6 tons. Sulphur content proved to be high, but was reduced by increasing the slag basicity. The design of the charging unit presented a problem. Experiments with oxygen enrichment, acid melting, and variations in size are in progress. The ores used contain 20–29% iron, and more than 46% silica.—L. J. L.

The Low-Shaft Blast Furnace. E. Cotel. (*Acta Techn.*, 1953, **7**, (3–4), 413–423). [In German]. The author advocates the use of low-shaft furnaces because full-scale experiments have proved them to be best for using low-grade coke. They will render the sintering of ores almost obsolete. (21 references).—R. P.

The Manufacture of Pure Iron by a Duplex Process of Bessemer Converter and High Frequency Electric Furnace. H. Kamura. (*Tetsu to Hagane*, 1951, **37**, July, 394–396). [In Japanese]. Molten pig from a cupola can be blown in a Bessemer converter, then refined in a high frequency electric furnaces, with acid slag, to give a metal with <0·02% of carbon, deoxidized to give good mechanical properties.

TREATMENT AND USE OF SLAGS

The Two-Stage Process for the Recovery of Manganese from Open-Hearth Slag. H. W. Hosking and J. A. Gregory. (Australian Inst. Metals: *Australasian Eng.*, 1953, Dec. 7, 48–57). This paper, which gives details of a full-scale production trial, is complementary to the earlier paper outlining the process previously published (*see J. Iron Steel Inst.*, 1954, **177**, July, 366). Both stages of the two-stage process have now been tested over a large tonnage of raw material, and the conditions for satisfactory selective reduction in large furnaces have been established and maintained over 100 heats. High recoveries of an alloy averaging 46% Mn and 20% Si were achieved. Full details are given of the composition of typical charges and products.—P. M. C.

The Use of Steel Plant By-products. E. H. Rose and J. F. Kimball. (*Amer. Iron Steel Inst. Regional Tech. Meetings*, 1953, 147–160). The authors discuss disposal and use of waste materials and by-products at the Tennessee Coal and Iron Division of United States Steel Corp. The chief materials considered are slag, coal washer refuse, spent pickle liquor, and flue dust, and mention is made of other waste materials from raw materials preparation, furnace and mill operations, and the coking plant.—G. F.

Mineral Wool Manufacture by Jet Blast of Liquid Slag. (*Indust. Heating*, 1954, **31**, Mar., 568–570). Details of an installation producing 30 tons/day are given. Local slag is remelted in a reverberatory furnace and discharged in ¼-in. streams in front of steam jets at 90 lb./sq. in.—R. W. B.

DIRECT PROCESSES

The Smelting of Iron Ores in the Rotary Furnace. W. Böddeker. (*Met. u. Giesserei Techn.*, 1954, **4**, Apr., 148–157). The Stürzelberg plant and its operation are described in detail. Advantages and drawbacks are listed. Points discussed are: (1) Insufficient reduction of phosphorus and silicon; (2) use of inferior fuel (coke and coal fines); (3) pig iron produced can be used in grey iron or steel castings; (4) fine ores can be used without difficulty; (5) ores containing volatiles, metals or alkalies can be smelted; and (6) carbon content can be adjusted at will. The drawbacks include considerable iron and manganese losses in the slag, the high costs of the process, and rather frequent plant breakdowns.

Kinetic Study of the Reduction of Ferric Oxide with Lignite. C. V. S. Ratnam. (*J. Sci. Indust. Res.*, 1953, **12**, Nov., 548–550). Reaction velocity constants have been determined for the reduction of ferric oxide with three forms of lignite and a coconut char. For one of the lignitic reducing agents an equation has been derived connecting the reaction velocity constant with temperature.—J. O. L.

PRODUCTION OF STEEL

Causes of Premature Failure of Silica Roofs in Open-Hearth Furnaces. S. Pavlowski. (*Hutnik*, 1954, **21**, (4), 91–100). [In Polish]. On the basis of the author's observations and published data, the causes of premature failure of silica brick open-hearth roofs are discussed.—V. G.

Taboos Slag Pocket Build Up. (*Steel*, 1954, **134**, Apr. 26, 112–115). A new design of open-hearth end construction is described. Deflectors and low gas velocity cause matter entrained in gas leaving the furnace to drop out in the slag pocket whence it is removed by steam jets. The construction is also designed to give even flow into the checkers. This improved design affords a decrease in tap-to-tap time, an increase in heat recovery, improved combustion, and the elimination of checker lancing.—D. L. C. P.

Progress in the Maintenance of Open-Hearth Furnaces. C. Joseph. (*Écho Mines*, 1954, Apr., 235–236). A short description is given of a method of repairing worn open-hearth brickwork by spraying a suspension of a refractory substance on the affected part whilst it is at a temperature between 1400° and 1500° C.—B. G. B.

Significance of Minor Elements in Iron-Bearing Raw

Materials for Integrated Steel Plants. C. B. Jacobs, J. F. Elliott, and M. Tenenbaum. (Amer. Iron Steel Inst.: *Blast Furn. Steel Plant*, 1954, **42**, June, 666–674, 679, 688). A detailed examination is made of the origin, elimination, and effect on the finished product of a wide range of elements which occur in minor amounts in iron ores used in the American steel industry. The relative stability of the metallic oxides is related to the reducing conditions which are found in sintering, oxidizing, and reducing electric steel furnace operation and the blast-furnace hearth.—B. G. B.

Convection and the Heating of Scrap. L. F. Daws and R. D. Collins. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 349–353). [This issue].

Use of Cold Coke-Oven Gas and Pitch–Creosote Firing on Tilting Furnaces. Development at Appleby-Frodingham. W. Jackson. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 375–387). [This issue].

High-Temperature Water Cooling of O.H. Furnaces by Steam-Producing Elements. F. J. Feltoe and P. M. Moreton. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 388–392). [This issue].

The Production of Physically Clean Steel—The P.A.P. Process—L.P. Coatings for Ingot Moulds. J. G. Platon. (*Rev. Mét.*, 1954, **51**, Feb., 109–114). After considering the factors governing the production of clean steels, a description is given of the P.A.P. (Procédé Aluminium Platon, a method of deoxidizing with liquid aluminium) process involving the addition of liquid aluminium to the oxidized steel. The dirty surfaces of ingots may, it is claimed, be eliminated by using the L.P. mould coating which acts by fluxing impurities and the limited evolution of gas.—A. G.

The Use of Granulated Ferromanganese. J. G. Platon. (*Rev. Mét.*, 1954, **51**, Feb., 108). The irregular results arising out of the use of granulated ferromanganese in steel-works are shown to be due to lack of care in avoiding the loss of this material in the slag.—A. G.

Desulphurization with Rare Earths. (J. A. Berger and M. G. Snellman. (Amer. Inst. Min. Met Eng.: *Steel*, 1954, **134**, Apr. 12, 110–117). Practical tests are described which were designed to give more information on the rare-earth–sulphur reaction in liquid steel. The main obstacle to its efficacy is the reversion of sulphur to the metal after the good initial desulphurization (up to 95%) which may be obtained. The effect of the steel deoxidizer, carbon and sulphur contents, temperature, the atmosphere, and the type of rare earth, on the rate and extent of desulphurization, and on the onset, rate, and extent of reversion were investigated.—D. L. C. P.

Rare Earth Additions Affect Surface Quality of Low Carbon Steel. J. V. Russell. (*J. Met.*, 1954, **6**, Apr., 438–442). Trials have been carried out at Republic Steel Corp. to evaluate the effect of rare-earth additions, particularly on surface quality of low carbon-steels. Rare-earth metal additions to ladle or mould effectively reduce the sulphur content with resulting improvement in surface quality in cases of low Mn/S ratios. Rare-earth oxides have little effect in this respect. With aluminium-killed steels, however, rare-earth metal additions greater than 2 lb./ton produce hot-shortness more severe than that due to aluminium alone, and cause deterioration in surface quality. The oxides have the reverse effect, due to oxidation of the aluminium.—G. F.

Thermodynamic Calculation of Slag Equilibria—II. Influence on Cation Exchange Equilibria Caused by Cations Not Taking Part in the Exchange. K. Grjotheim. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 354–356). [This issue].

Some Statistical Methods Used in Studies of Steel Plant Operations. A. P. Woods. (Amer. Iron Steel Inst.: *Blast Furn. Steel Plant*, 1954, **42**, June, 649–652, 665). The application of statistical methods to the steelmaking process is discussed. An example of the analysis of basic open-hearth furnace data to determine the effect of certain operating factors on the rate of production is given.—B. G. B.

Steelmaking Processes—Some Future Prospects. C. D. King. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Apr., 455–465). The author considers the practical phases of various steelmaking processes, giving particular attention to the more recent developments such as the 'turbo-hearth,' the downward blown oxygen process (at Linz), and the Perrin modifications. The relative importance of these methods to meet specific needs is discussed and the possible forms that future ingot processes will take is considered.—G. F.

FOUNDRY PRACTICE

Synthetic Iron and Its Use in Making Malleable and Spheroidal Graphite Irons. M. Guedras. (*Mét. Constr. Mécan.*, 1954, **86**, Apr., 285–287). The practice of manufacturing malleable and spheroidal type irons from scrap iron melted in a cupola is discussed.—B. G. B.

Three Years of Cast Iron with Spheroidal Graphite in West Germany. K. Figge. (*Giesserei*, 1954, **41**, Apr. 15, 193–198). Only three years after it had been introduced into Germany, cast iron with spheroidal graphite can today be manufactured in a reproducible and economic manner. In the beginning there were numerous difficulties which had to be solved, with regard to raw materials, melting furnaces, and the operation of the magnesium method. The properties and uses of the material are described and illustrated with numerous examples.

Observations on the Ladle Treatment of Cast Irons with Metallic Magnesium. A. Wittmoser. (*Giesserei*, 1954, **41**, Mar. 4, 105–108). The economic basis for the manufacture of cast iron with spheroidal graphite by the addition of pure magnesium or high magnesium alloys to the ladle is discussed. Several devices for introducing the magnesium or magnesium alloy into the ladle are described and illustrated, full details being given of a tilting holding vessel with an arrangement for injecting the alloy into the liquid iron by compressed air or nitrogen.—R. A. R.

Effects of Magnesium on Eutectic Modification and Graphitization of Certain Fe–C Alloys. H. W. Weart and R. W. Heine. (*Trans. Amer. Found. Soc.*, 1953, **61**, 674–677). In a study of a series of Fe–C–Mg alloys with magnesium contents of up to 0·125%, it was found that magnesium causes a coarser distribution of austenite and carbide in the ledeburite eutectic, and, in heat-treated specimens, gives rise to nearly spheroidal graphite instead of the irregular flakes present in the magnesium-free alloy. Spheroidal graphite was also produced by magnesium in a hypereutectic alloy in the as-cast condition. The presence of silicon, manganese, sulphur, and phosphorus does not appear to be essential for the formation of either the modified eutectic or spheroidal graphite.—B. C. W.

Hardening Characteristics of Induction Heated Ductile Iron. E. P. Rowady, W. J. Murphy, and J. F. Libsch. (*Trans. Amer. Found. Soc.*, 1953, **61**, 422–431). The hardening characteristics of induction heated spheroidal graphite cast iron have been investigated as a function of the original structure and the austenitizing conditions. The response to induction hardening increases with the amount of pearlite, the austenitizing temperature and time, and the amount of spheroidal graphite. An instantaneous response only appears to occur with pearlitic ferritic structures. The results indicate that surface hardening of spheroidal graphite iron should give a casting with a surface hardness of about Rockwell C60 with at the same time good core properties. Isothermal transformation diagrams are also presented for two of the ductile irons.—B. C. W.

Effect of Prebaking in Malleablizing Iron. F. Brown. (*Amer. Foundryman*, 1954, **25**, Feb., 50–51). Results are presented to show that isothermal treatment of white cast iron at temperatures below 700° C. produces graphite nuclei which are then available for subsequent first-stage malleablization. The sub-critical nucleation of graphite shows a maximum rate at about 400° C. which is attributed to the interaction of carbide spheroidization and carbon diffusion. It is found that hydrogen inhibits the nucleation of graphite.—B. C. W.

Fundamentals of Heat-Treatment of Gray Cast Iron. J. E. LaBelle. (*Trans. Amer. Found. Soc.*, 1953, **61**, 643–645). The elementary principles involved in the formation of graphite and in the hardening and tempering of cast iron are very briefly discussed.—B. C. W.

Notes on Air Furnace Design and Operation. J. E. Rehder. (*Trans. Amer. Found. Soc.*, 1953, **61**, 516–522). A discussion is given of the design, operation and maintenance of reverberatory furnaces used in the production of malleable iron. The operating practice refers principally to pulverized-coal-fired furnaces used for duplexing.—B. C. W.

Graphitization in the Malleable Iron Industry. H. A. Schwartz, W. K. Bock, and J. D. Hedberg. (*Trans. Amer. Found. Soc.*, 1953, **61**, 228–242). A detailed statistical study is presented of the composition factors affecting graphitization rate in all the various stages of malleablization. The main conclusions reached are: (*a*) The deposition of graphite from

the liquid is only a function of carbon, silicon, and time of freezing; (*b*) first-stage annealing rate is determined predominantly by silicon; and (*c*) the conversion of austenite to ferrite and graphite is the fastest of the graphitization processes and its rate is primarily a function of silicon content.

Experiment on the Pouring of Steel. A. A. Savchenko. (*Liteĭnoe Proizvodstvo*, 1954, (2), 27). [In Russian]. Ladle stoppers and procedure for facilitating the pouring of steel in the foundry are briefly described.—S. K.

Anti-Sticking Mould Mixtures for Stainless Steel Castings. I. R. Kryanin, A. M. Lyass, V. O. Yakovlev, I. B. Kumanin, and P. A. Borsuk. (*Liteĭnoe Proizvodstvo*, 1954, (2), 3–7). [In Russian]. After a consideration of the factors promoting adhesion of mould mixtures to stainless steel castings, an account is given of experiments with various anti-sticking mixtures. Best results were obtained with chrome–magnesite mixtures (especially when mixed with water-glass). Full-scale tests showed that for large castings the mixture should be applied in a 15–20 mm. thick layer using an underlayer of high gas-permeability. Curves are presented showing the effects of various factors on the strength of the chrome-magnesite mixtures.—S. K.

Mould Dressings. O. Bohuš. (*Hutník*, (Prague), 1954, **4**, (4), 105–106). [In Czech]. The functions, compositions and quality of dressings for steelworks ingot moulds are discussed.

Cement Sand As a Moulding Material. H. G. Levelink. (*Metalen*, 1954, **9**, Apr. 30, 121–125). A summary is presented of answers to a questionnaire to Dutch foundries on their methods of preparing cement sand moulds.—R. A. R.

Reactions at the Surface of Moulds. H. Reininger. (*Giesserei*, 1954, **41**, Mar. 4, 109–110). This paper is concerned mainly with the formation of dust by the splitting of quartz grains in moulding sand on casting. Both natural and a synthetic bentonite-quartz moulding sand are considered. The cause of this wearing of the sand when iron or steel is cast into a sand mould is illustrated schematically. At the casting-sand interface there is the reaction zone where marked chemical and physical changes in the sand occur, next to this is the zone where the sand sinters, next comes the dust-forming zone, and finally the zone where the temperature of the casting does not affect the sand. (11 references).—R. J. W.

Investigation on Moulding Sand. E. Wagner, H. Schlichtenmayer, H. Staud, and G. Weber. (*Giesserei*, 1954, **41**, Mar. 4, 111–113). The effect of additions of Vermiculite with a specific water content on the gas permeability, and the compression and shear strengths of synthetic moulding sands with different bentonite contents was investigated. In further experiments the dependence of the properties of similar sand mixtures on the moisture content was examined. Finally, two mixtures of a synthetic sand with a certain binder were compared when different amounts of water were added.—R. J. W.

How Far Should We Go in Foundry Sand Control. E. E. Woodliff. (*Amer. Foundryman*, 1954, **25**, Feb., 60–65). The fundamentals governing the choice of moulding sand are discussed together with the sand variables that affect the quality of the casting. The extent to which each of the variables should be controlled is then considered.—B. C. W.

Research on Blending of Very Fine Particles in the Moulding Sand. H. Nisihara. (*Tetsu to Hagane*, 1951, **37**, Dec., 642–652). [In Japanese]. Investigations were made of the effect of very fine particles, by blending and measuring the permeability and strength of the sand.—K. E. J.

Contribution to the Knowledge of Foundry Sands. M. Arrighetti. (*Fonderia Ital.*, 1954, **3**, Feb., 69–73). [In Italian]. The author reviews papers published in Italy on refractory sands, and discusses the problems which have to be overcome in the light of recent research. All the physical and chemical characteristics of these sands are examined, as well as the requirements and advantages of synthetic sands. (37 references).—M. D. J. B.

Investigation of Properties of Steel Sands at Elevated Temperatures. R. G. Thorpe, H. Robinson, P. J. Wisniewski, and P. E. Kyle. (*Trans. Amer. Found. Soc.*, 1953, **61**, 96–106). Stress-strain and expansion data over the range 1000–2400° F. (540–1320° C.) are presented for eleven synthetic steel sand mixtures, together with results for the hot compressive strength at 2500° F. (1370° C.) and the room temperature properties. Five of the mixtures were investigated with respect to scabbing tendency.—B. C. W.

Report of A.F.S. Flowability Committee. (*Trans. Amer. Found. Soc.*, 1953, **61**, 156–158). Flowability is defined as the ability of a moulding material to form a uniformly compacted surface, and visual standards are shown for both unriddled and riddled sand. A suggested flowability test procedure is described in detail.—B. C. W.

Development of Foundry Sand Reclamation. C. E. Wenninger. (*Trans. Amer. Found. Soc.*, 1953, **61**, 191–195). The historical development of foundry sand reclamation is traced and the fundamental principles involved in sand deterioration and rejuvenation are outlined. The faults of several past reclamation methods are discussed and the requirements of a satisfactory system stated.—B. C. W.

Reclamation of Sand by Pneumatic Dry Scrubbing. H. W. Meyer. (*Trans. Amer. Found. Soc.*, 1953, **61**, 196–199). The type of coating on sand grains was found to affect profoundly the thermal shock characteristics of the sand. Heavily coated, non-uniformly coated and non-coated grains gave poor results while medium, thin, or smear coatings were ideal. Realization of this effect enabled mulling practice to be improved and led to the choice of a pneumatic dry scrubbing unit for reclaiming used sand. The rubbing of sand grains together uniformly reduced the coating thickness whilst impact reclaiming gave non-uniform removal.—B. C. W.

A Wet Method of Sand Reclamation. P. C. Will and R. H. Shurmer. (*Trans. Amer. Found. Soc.*, 1953, **61**, 206–210). A pilot plant for wet reclamation of foundry sand is described and results are given for 32 waste foundry sands to show that the properties of the reclaimed sand compare favourably with those of new sand. Foundry tests on the reclaimed sand have shown that casting quality is not affected by its use in place of new sand —B. C. W.

Sand Reclamation in a Steel Foundry. H. H. Johnson, R. Y. McCleery, and G. A. Fisher. (*Trans. Amer. Found. Soc.*, 1953, **61**, 211–221). The wet method of sand reclamation in use at the National Malleable and Steel Castings Co., Sharon, Pa., is briefly described and operating experiences with it are discussed. Quality control charts covering the period before and after the introduction of the reclaimed sand are presented and discussed, and the operating precautions found necessary with the reclamation unit are briefly considered. The authors conclude that the system has been economically justified as well as technically successful.–B. C. W.

Sand Reclamation with the Combination System. G. H. Curtis. (*Trans. Amer. Found. Soc.*, 1953, **61**, 222–227). The combination system for sand reclamation involves the removal of clay by water scrubbing followed by the burning off of the organic matter in an oxidizing atmosphere. The system is described and discussed, and the advantages, costs and space requirements considered.—B. C. W.

Factors Involved in Making a Sand Mixture: Preliminary Study No. 1. D. F. Baker and D. C. Williams. (*Trans. Amer. Found. Soc.*, 1953, **61**, 309–314). The energy absorbed in mixing clay–sand–water mixtures has been determined under different conditions. The addition of kerosene to sand–water mixtures reduced the energy required.—B. C. W.

Feeding and Solidification of Castings. K. Åkesson. (*Gjuteriet*, 1953, **43**, Dec., 209–221; 1954, **44**, Jan., 1–10; Mar., 43–50). [In Swedish]. Part 1: Based on a critical survey of literature, the author examines the influence on solidification of position and movement of isotherms, dendrite formation, and sedimentation. Principles of controlled solidification are discussed and details given of the influence of casting shape, feeding system, pouring rate and temperature, and the thermal characteristics of the moulding materials. Part 2: Factors governing feeding pressure discussed include: Static pressure of metal, use of Kayell's mixture, and centrifugal pressure. Tests made to increase the feeding range of risers with castings of uniform thickness are outlined. Methods of delaying solidification are reviewed aud brief details given of gating techniques to ensure balanced feed systems. Part 3: In a review of feeders and neck cores, the functions and use of atmospheric feeders are discussed, a comparison being made with ordinary risers. Details are given of tests to establish the influence of neck cores on feeding.—G. G. K.

Calculating the Dimensions of Runners and Gates. (*Giesserei*, 1954, **41**, Apr. 15, 207–208). In accordance with the latest views it is recommended that the flow cross section of sprues, runners, and gates be changed from their previous ratio of 1 : 4 : 4 to 1 : 6 : 6, and further that the cross-section of each gate be made less than that of the one before it. The aim of this change is to reduce the rate of flow on the metal

in the runners and in the entrance to the moulds. Several numerical examples are given and illustrated.—R. J. W.

Fundamentals of Riser Behavior. C. M. Adams, jun., and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1953, **61**, 686–693). In order to obtain a simple quantitative method of determining riser size a mathematical analysis was made of the solidification using a model. This led to the equation

$$(1 - \beta)\frac{V_r}{V_c} = \frac{A_r}{A_c} + \beta,$$

where β is %-shrinkage/100, and V_r, A_r, V_c, and A_c are the volumes and surface areas of riser and casting respectively. The modifying effects on this simple equation of chills, insulators, radiation, casting and riser shape, superheat, and "mushy" freezing are then considered. The theory is found to agree well with Caine's results for steel castings.—B. C. W.

Solidification at Corner and Core Positions. F. A. Brandt, H. F. Bishop, and W. S. Pellini. (*Trans. Amer. Found. Soc.*, 1953, **61**, 451–456). The solidification of **L** and **T** section steel plates and that of hollow cylinders was followed by thermal analysis. The solidification times for these plates were $1\frac{1}{3}$ and $1\frac{1}{2}$ times longer than for flat plates. With the cylinders the greatest increase in solidification time over that for a flat plate of equivalent thickness, was 15% for internal diameters of $\frac{1}{4}$ to $\frac{1}{2}$ the wall thickness. The effects of casting shape on the rate of heat flow from casting to sand which determines solidification rates are shown to be related to the divergency or convergency of heat flow patterns in the sand.—B. C. W.

The Study of Vertical Gating. Progress Report. K. Grube, J. G. Kura, and J. H. Jackson. (*Trans. Amer. Found. Soc.*, 1953, **61**, 81–95). Results are presented of a photographic study of conventional vertical gating systems using transparent models with water as the liquid. The two models were of large and small plate castings and six basic sprue designs were used with both rectangular and circular cross-sections. A tapered sprue for the larger mould and rectangular sprues for the smaller mould showed some advantage in reducing turbulence. The rectangular sprue which delivered liquid through the mould bottom gave less trapped gas than the side-entry sprues. A large number of photographs showing the liquid entering and filling the models are presented.

Fusion of Chaplets. K. E. Strand. (*Gjuteriet*, 1954, **44**, Apr., 63–65). [In Swedish]. During tests to determine factors governing the fusion between chaplets and grey-iron castings, attention was concentrated on the influence of the chaplet tin coating. Chaplets used were 6 mm. high and 2 mm. in dia., the tin coating varying between 0·6 and 8·0 μ. Best results were achieved at 8 μ. Mechanism of fusion between the metal and chaplet is described and good and bad fusion zones are illustrated.—G. G. K.

Weights on Large Moulds. S. Jouza. (*Slévárenství*, 1954, **2**, (4), 102–104). [In Czech]. Copes on large moulds are often fastened down by weights, which may be heavier than the casting. A method is described in which the weights are replaced by transverse steel beams held by yokes. The advantages of this method are: (1) Reduced danger of damaging the mould; (2) easy manipulation, and (3) less demand for the use of cranes.—P. F.

Considerations on the Construction of Moulding Machines Driven by Compressed Air. J. Broberg and L. Villner. (*Giesserei*, 1954, **41**, Mar. 18, 129–134; Apr. 1, 153–160). The operation of moulding machines is first considered, including such details as the material, weight, and strength of different portions of the machine, special attention being paid to the compressed air system. Constructional details of several moulding machines are then described. Suggestions are made to improve present machines. (31 photographs and diagrams).

Dielectric Core Baking. K. Wirta. (*Gjuteriet*, 1954, **44**, Apr., 55–62). [In Swedish]. Tests on a Swedish H.F. dielectric heating oven for core baking, capacity 1100 lb./hr., are described, and a cost comparison is made between this method and gas heating. Core sands with varying resin, starch and water contents were baked and the effects of *p*H value and mixing times studied. Hints are given on core rodding and coating and material for core plates and driers. It is shown that oil–sand mixtures are not suitable for this treatment.

Experimental Mechanization and Improvement of the Technology of Casting by the Lost-Wax Process. N. S. Kreshchanovskii, M. L. Khenkin, N. K. Levina, and M. N. Zimmering. (*Liteĭnoe Proizvodstvo*, 1954, (2), 8–11). [In Russian]. Experiments on the mechanization and improvement of the following stages in the production of steel castings by the lost-wax process are described: Production of pressure-moulds, preparation of the special wax, preparation and drying of the ceramic coating, melting-out of the wax, calcination of the moulds, and the cleaning of the castings. The adoption of the methods described is said to have given a four-fold increase in production.—S. K.

The Austenal Lost-Wax Process. H. J. Marshall. (*Giesserei*, 1954, **41**, Mar. 4, 120–123). The history of the lost-wax process is briefly traced. The method of manufacturing precision cast pieces by the lost-wax process is then described. Several photographs illustrate different parts of the process. Economic production possibilities of the process are considered and illustrated. The advantages and limitations of this method are described, with data on the tolerances. Appreciable saving of metal can be effected by this process, the amount depending on the application. The mechanical properties of six different cast steels are tabulated.—R. J. W.

Centrifugal Casting Process Produces 10 ft.-long Cylinder Liners. (*Machinist*, 1954, **98**, Apr. 10, 625–626). Considerable cost saving and technical advantages are claimed for the new Burlington centrifugal casting process adopted by Sheepbridge Eng. Ltd. for the production of cylinder liners. Using this technique, single and bi-metal castings up to 10 ft. long, up to 20 in. in dia. in steel and 30 in. in cast iron will be produced initially.—M. A. K.

Engineering Aspects of Centrifugal Casting. J. F. Wallace. (*Trans. Amer. Found. Soc.*, 1953, **61**, 701–718). A comprehensive review is presented of the methods and machines used in the production of true centrifugal, semi-centrifugal, and centrifuged castings. In true centrifugal casting at least part of the useful inside surface is formed by centrifugal force, while in the semi-centrifugal process the entire shape of the casting is formed by the mould. Centrifuged castings are not rotated about their own axis but about a central sprue which feeds a large number of identical moulds. The advantages and disadvantages of each process are considered and particular attention is paid to the defects that may occur in centrifugal castings.—B. C. W.

New Techniques Shorten Investment Casting Cycle. W. G. Patton. (*Iron Age*, 1954, **173**, Jan. 28, 115–117). A short cycle investment casting process that offers all the advantages of the lost-wax process plus high production has been developed for precision castings. A new precoating material that resists heat shock, the use of plastic patterns, and centrifugal casting all help to reduce the time cycle. Small, high strength parts can readily be cast to a tolerance of 0·006 in.—A. M. F.

Two New Ways to Fasten Shell Mold Halves. (*Precision Met. Mold.*, 1954, **12**, Apr., 99–100).

Scientific Method in Industry—Shell Moulding. M. J. Sargeaunt. (*Machinery Lloyd*, 1954, **26**, May 29, 54–68). The advantages of using simple physical concepts in the analysis of industrial processes before making important decisions are discussed with particular reference to the investment process in shell moulding. The principles involved in this process are considered in detail and the conclusions that can be drawn from such a study are listed.—L. E. W.

Modern Methods of Production in British Foundries with Special Reference to the Shell Moulding Process. A. S. Beech. (*Inst. Hierro Acero*, 1954, **7**, Jan.-Mar., 14–27). [In Spanish]. Details of modern practice are described. Manipulation of sand is discussed. Modern moulding machines are described, and, in particular, the automatic technique of extraction from the mould used by the British Railways. Attention is drawn to the dimensional precision, surface finish, and soundness of the castings made by shell moulding as well as the greater yield given by the process.—C. B. L.

Pattern Equipment for Shell Moulding. O. C. Bueg. (*Trans. Amer. Found. Soc.*, 1953, **61**, 729–730). Details are given of a recommended procedure for designing and producing pattern equipment intended for shell moulding.—B. C. W.

Agar Gels in Plaster-Bonded Investment. H. Rosenthal and S. Lipson. (*Trans. Amer. Found. Soc.*, 1953, **61**, 347–351). The addition of 0·2% by weight of agar to a 70/30 silica–gypsum investment thickens the slurry so that there is no appreciable loss by drainage. The use of agar also suppresses the collection of free water on the underside of the patterns when the mix is used as a single coat investment.—B. C. W.

Hot Plastic Moulding in Closed Dies of Cast Irons and Steels with more than 1·7% C. W. Schlegel-Velbert. (*Ing. Mecc.*, 1953, **2**, Dec., 27–34). [In Italian]. This paper describes a

new process for manufacturing finished cast iron or steel parts by means of a press and closed moulds. The quality of the hot plastic pressings is such as to make subsequent machining unnecessary. Though the chemical and physical qualities of the cast iron remain unchanged, its tensile strength, it is claimed, is increased two to three times. The principle of the process is described in detail and information is given on mould shape, pressures, and temperatures. Results of tests on different qualities of cast iron are given and the technical and economic advantages are discussed.—M. D. J. B.

The Foundry at Wilton-Fijenoord. G. J. Dumont. (*Handel en Industrie, (Supplement to Metalen)*, 1954, **9**, Apr. 15, 62–64). [In Dutch]. The author gives an account of the development of the two foundries from the early part of the nineteenth century. Latterly, after modernization, operations have been extended to castings for the motor industry.—F. R. H.

High Vacuum Equipment: Pumping Systems Require Close Attention. G. P. Gerow. (*Iron Age*, 1954, **173**, Feb. 18, 142–144). The selection of vacuum equipment for metallurgical processes, mainly melting under vacuum, is discussed. For operating in the general pressure range, an oil–vapour ejector supported by a mechanical forepump is favoured. To reduce pumping time in rapid batch processing a backing pump may be added. Steam ejectors are desirable if contamination is a problem. Close attention must be paid to gaskets and welds.—A. M. F.

Convection in Molten Metals. L. I. Sokol'skaya. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1949, (9), 1365–1371). Using stearine, the temperature distribution in the top and bottom of cast cylinders was studied. Owing to convection, the temperature of the top part of a casting was higher than that of the bottom. This was also confirmed by bleeding experimental grey iron castings and by measuring the temperature distribution in cylindrical steel castings. The importance of convection currents in the solidification of cast metals is discussed.—V. G.

The Practical Use of a Three-Dimensional Weichelt Diagram for Alloyed Cast Iron. A. W. Van der Bergh. (*Metalen*, 1954, **9**, Apr. 15, 103–106). [In English]. The author discusses the solidification phenomena and the manner in which alloying elements and wall thickness affect the structure. Three-dimensional diagrams are constructed to show the relationships between the carbon content, relative silicon content, and the casting thickness.—R. A. R.

Control of Casting Surfaces. O. Morávek. (*Slévárenství*, 1954, **2**, (4), 104–106). [In Czech]. Current methods of crack detection in castings are briefly surveyed. A rapid method, requiring about 5 min., which has proved very satisfactory is described. The casting is submerged in an oil-petrol mixture and subsequently degreased by exposure to trichloro-ethylene vapours in a chamber for 2–3 min. The casting is then dried in air, and the solution which had entered cracks during the degreasing stage, oozes out and reveals the position of the cracks.—P. F.

Gas Porosity in Castings—Gassing and Degassing Melts. G. Schweitzke. (*Giesserei*, 1954, **41**, May 13, 254–261). Methods of reducing porosity in castings and the effects of SO_2, CO_2, CO, hydrogen, and oxygen are discussed and some experiments relating mainly to non-ferrous metals are reported. The work of P. Bastien on the solubility of hydrogen and nitrogen is referred to. (29 references).—R. A. R.

Heat Conducting Anti-Piping Compounds. B. Tisza. (*Giesserei*, 1954, **41**, Mar. 18, 142–147). The advantages of heat insulating, and exothermic compounds added to the risers are described. These additions enable considerably smaller risers to be employed. Six properties necessary for a satisfactory compound are listed and considered in detail.

Organizing Methods of Preventing Rejects in an Iron Foundry. S. Pelczarski. (*Przeglad Odlewnictwa*, 1954, **4**, (3), 68–76). [In Polish]. The organization of the control of foundry production and the co-operation between various departments of a foundry necessary to diminish the number of defective castings are discussed.—V. G.

The Influence of the Quality of Moulding and Core Sands on Defects in Grey Iron Castings. K. Hess and Z. Wertz. (*Przeglad Odlewnictwa*, 1954, **4**, (3), 59–68). [In Polish]. The dependence of the appearance of defects on the properties of sands and the dependence of these properties in turn on inherent factors are presented in tables, and the relationship is discussed.—V. G.

Trends for the Relation of Chill Test Depth and Carbon Equivalent of Gray Cast Irons. E. A. Loria. (*Trans. Amer. Found. Soc.*, 1953, **61**, 387–393). The chill depth for grey cast irons produced in two foundries was correlated with the carbon and silicon contents of the iron. A wide scatter band was obtained for chill depth plotted against total carbon plus one-third silicon content, but the scatter was reduced if the results were selected on the basis of a constant total-carbon/silicon ratio. A linear correlation with still less scatter was found to exist between chill depth and total carbon plus one-and-a-half times the silicon.—B. C. W.

Solidification of Cylinders. V. Paschkis. (*Trans. Amer. Found. Soc.*, 1953, **61**, 142–149). Results are given of heat flow calculations for the solidification of long and short cylinders. It was assumed that the surface of the casting remained at the Riemann temperature throughout solidification. Assuming that solidification time is proportional to $(V/S)^2$, where V is the volume and S the surface area of the casting, the calculated results were found to agree closely with experimental data. The computation and significance of the Riemann temperature are discussed in appendices.

Fork-Lift Truck Systems Speed Wheel Production. L. W. Bennett and S. Davis. (*Amer. Foundryman*, 1954, **25**, Feb., 36–39). The use of fork-lift trucks in handling castings, foundry supplies, and scrap in a wheel foundry is illustrated and discussed. The trucks have the great advantage that they can be used as an emergency source of power during either power cuts or the mechanical failure of particular pieces of equipment.—B. C. W.

Calculating Production Costs in the Foundry. S. Bellone. (*Fonderia Ital.*, 1954, **3**, Feb., 65–68). [In Italian]. The author discusses production costs in small and medium sized foundries which have limited technical staff and which are engaged in jobbing work and are capable of producing iron and steel castings of various sizes.—M. D. J. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Full-Scale Manufacture of High Quality Springs. A. G. Ligier. (*Usine Nouvelle*, 1954, **9**, Jan. 7, 25–27). The two methods of hot and cold fabrication are outlined and the essential operations described in the light of the precautions to be taken. These include ensuring minimum decarburization during heating, appropriate quenching and tempering, pre-stressing, and pre-setting.—A. G.

Gas-Heated Shaft Furnaces for the Heat-Treatment of Steel. H. Bühler. (*Stahl u. Eisen*, 1954, **74**, May 20, 726–729). The construction and operation of vertical shaft furnaces for heat-treating elongated objects, such as shafts, tubes, and turbine rotors, are described. The advantage to be gained from this type of furnace, which can be heated up at any desired rate, and heat input regulated to various parts so that objects of varying cross section can be uniformly heated, is that the objects suspended therein do not bend or distort. The oil and water quenching tanks and their pumping, cooling, and filtration gear are also described.—J. P.

Heat Treatment and Materials. (*Machinist*, 1954, **98**, May 22, 899–906). This commentary, relating to the heat-treatment in the modern gauge and toolmaking industry, expresses the individual views of a steel producer, a user, and a manufacturer of heat-treatment equipment. A description of some heat-treatment methods used by Rolls Royce Ltd. including a deep-freeze unit for improving tool life is given.—M. A. K.

Heat Treatment in the Machine Shop by the Cassel Salt Bath Method. (*Machinist*, 1954, **98**, May 29, 961–963). The need for reducing distortion, maintaining a clean, scale-free surface and eliminating decarburization has resulted in a salt bath treatment becoming widely used, as many tools, complicated in section, cannot be corrected by grinding after heat treatment. Typical installations are described.—M. A. K.

Let Modern Heat Treatment Turn on the Heat to Turn Down Your Costs. A. G. Gray. (*Steel*, 1954, **134**, Mar. 29, 102–105). This is a review of modern U.S. practice in many aspects of heat-treatment. Examples are given of recent developments in the economical combination of materials and heat-treatment for producing many types of part.

Resistance of Cast Fe–Ni–Cr Alloys to Corrosion in Molten Neutral Heat-Treating Salts. J. H. Jackson and M. H. LaChance. (*Trans. Amer. Soc. Metals*, 1954, **46**, 157–183). The authors give details and results of research designed to throw light on the corrosion of cast stainless alloy salt-bath pots by the molten salts. The objectives were: (1) To assess the

resistance to corrosion of various alloys; (2) to suggest alloys having increased corrosion resistance; (3) to evaluate the effects of both composition and operating variables. The second aim is achieved, but the better materials may sometimes present other difficulties. It was found that sludge on the bottom of an alloy pot would be important and detrimental.—D. L. C. P.

Case-Hardening of Steels. C. San Jose Seigland. (*Met y Elec.*, 1954, **18**, Jan., 42–49; Mar., 52–59). [In Spanish]. This is a summary of the art of case-hardening. Sections are devoted to the factors affecting the process, carburizing materials and how they act, case-hardening steels and how to select them, carburization in solid, liquid and gaseous media, and case defects.—C. B. L.

Determination of Depth of Hardening in Case-Hardening Steels. H. Müller. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 125–133). The depth of hardening in several case-hardened steels has been determined in five ways: (1) Examination of a fracture; (2) macroscopic and (3) microscopic examination of an etched section; (4) scratch test; and (5) hardness-depth curve determined with a Vickers hardness machine with a 10-kg. load. The following results were obtained: Microscopical examination of a polished section is frequently unsatisfactory and is too lengthy a process for practical purposes. The depth of hardness determined by the scratch hardness test is generally much greater than that indicated by the other methods and does not correspond to any definite point on the hardness-depth curve. The hardness-depth curve is reproducible only over its earlier part, *i.e.*, down to a value of 500 (Vickers). The depths of hardening determined on fractures and by macroscopic examination of etched sections exhibit large variations, of the same order.

Internal Stresses Due to Flame Hardening. H. Bühler. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 153–158). Cylinders of 0·31% and 0·50% carbon steels have been flame-hardened with oxy-coal gas or oxy-acetylene flames progressing along the rotating cylinder. A definite relationship was found between the depth of hardening and the magnitude and distribution of internal stresses over the cross-section. A connection was also found between the internal stresses after a conventional water hardening treatment and after flame-hardening of unalloyed structural steels. The reduction of internal stress after stress relief heating at 180° and 230° C. was determined. Stress relief periods in excess of those normally employed cause no further change in internal stress. The stress relief obtained on flame-hardened cylinders is of the same order as that from the same treatment of water-hardened specimens.—J. P.

Optimal Hardening Temperatures for Steel in Rapid Electric Heating. V. M. Zalkin. (*Stanki i Instrument*, 1954, (1), 16–17). [In Russian]. An account is given of experiments on specimens of structural and tool steels hardened from temperatures rising from 750° by 30° intervals to 1200° C. For each type of steel, heating rates of 50, 160, and 350° C./sec. were used. The specimens were heated by the passage of an electric current, automatically regulated with the aid of a photopyrometer. The initial and hardened microstructures and hardness were determined and diagrams based on these results are presented showing the optimum range of hardening temperatures against rate of heating for each steel.—S. K.

Investigations of the Heating of Charges in Annealing Furnaces. S. Herbst. (*Elektrowärme Techn.*, 1954, **5**, (3–4), 59–63). Nomograms for determining the rate of heat transfer by radiation, conduction and convection from the heat input and the temperatures and dimensions of the furnaces and of the charge are developed, and an example of their use is presented.—P. F.

Stress Relief Heat-Treatment of Grey Cast Iron. J. H. Schaum. (*Trans. Amer. Found. Soc.*, 1953, **61**, 646–650). The development of internal stresses in castings is explained and stress relaxation curves are presented to show the effect of temperature, initial stress, and alloy content on the removal of internal stress.—B. C. W.

Annealing Iron Castings for Machinability. A. W. Demmler. (*Trans. Amer. Found. Soc.*, 1953, **61**, 651–653). The factors affecting the machinability of cast iron are briefly discussed.

Design, Working and Operation of Bell Type Annealing Furnaces with Circulation of a Protective Gas Atmosphere and Heat Conducting Plates. O. Meurer, H. Fechner, and H. Pannek. (*Iron Steel Inst. Translation Miscellaneous Series* 216, 1954). This is an English translation of a paper which appeared in *Stahl u. Eisen*, 1953, **73**, Jan. 29, 158–165.

Effect of Ultrasonics on the Tempering of Metals. J. Palmé. (*Métaux-Corrosion-Indust.*, 1954, **29**, Mar., 100–104). Experiments have been carried out to investigate the tempering of metals in oil or water baths agitated by ultrasonic methods. The violent agitation was found to increase the rate of cooling, and if precautions were not taken the samples were hardened too much. In the case of oil quenching and with large samples, an increase in the hardness was accompanied by a finer crystalline structure of the metal and an increase in the resilience. The effect of ultrasonic vibration on the structure of metals is discussed.—B. G. B.

FORGING, STAMPING, DRAWING, AND PRESSING

The Casting, Forging, and Working of High Pressure Vessels from the Solid. (*Handel en Industrie, Supplement to Metalen*, 1954, **9**, Apr. 15, 65–68; Apr. 30, 70–72). [In Dutch]. An illustrated description is given of the English Steel Corporation's method of producing high pressure vessels from the ingot.—F. R. H.

Heavy Forges in Spain—Some of their Products. M. Puebla Camino. (*J. de la Grosse Forge*, 1952, 288–303: *Inst. Hierro Acero*, 1954, **7**, Jan.-Mar., 103–106). [In Spanish]. The number and sizes of the large forging presses in Spain is given (2 at 3000 tons, 1 at 2000 tons, 3 at 1800 tons, 1 at 1200 tons, 1 at 1000 tons). A description is given of the methods used for forging a diesel engine shaft, with details of the heat-treatment.—C. B. L.

7,000 Ton Forging Press. H. Ulmann. (*Eng. J.*, 1954, **37**, May, 557–563). The press at Trenton Steel Works was designed for the production of large ingots and billets, as well as for forming heavy plate, and contributes greatly to Canada's productive independence. Its rigidity and simplicity of operation are noted, and the thread design, pressure fluid, pumps, accumulator, and valves are discussed.—K. E. J.

Stamping Steel with Tools of Plastic Material. (*Usine Nouvelle*, 1954, **9**, Jan. 14, 29). These tools are made in aluminium moulds with a highly polished surface from a mixture of 50% polyester and 50% glass. Their advantages are that they can be made by unskilled labour, are light and easily repairable, and the cost is one-tenth that of steel tools.—A. G.

Modern Processes of Pressing. (*Usine Nouvelle*, 1954, **9**, Jan. 21, 53). A description of a French automatic press of completely new design is given. Irrespective of the degree of wear, vertical play and the risk of the plunger penetrating the mould are eliminated. Speeds of 125 to 400 blows/min. are possible.—A. G.

Tools for Shaping Thin Sheet Metals. R. Dupas. (*Mét. Constr. Mécan.*, 1954, **86**, Mar., 179–183). The design of tools for the bending and shaping of thin sheet metals is discussed. Examples of tools suitable for particular operations are given, and detailed drawings of their construction are reproduced.

The Heavy Pressing Industry in France. (*Mét. Constr. Mécan.*, 1954, **86**, Mar., 171–177). A description of the French industry for pressing and shaping large steel plates, and the equipment used, is given. Examples of the work, which includes gas cylinders, alternator casings, automobile bodies, and locomotive boilers, are considered.—B. G. B.

Production of Screws by Cold Pressing. H. Sojka. (*Hutnické Listy*, 1954, **9**, (3), 150–157; (4), 223–228). [In Czech]. A detailed account is given of the development of methods of cold pressing screws and bolts. The theory, the types of steel required, and the heat-treatment are discussed. Capacity of presses, dimensions of blanks, inspection and testing of products, common faults, and their origin and prevention are considered with particular reference to Czechoslovakian and German steels.—P. F.

Know the Wrinkles About Spherical Shells. S. R. Cope. (*Machinist*, 1954, **98**, Apr. 10, 616–620). Spherical and oval shells are often difficult to draw without wrinkles because of the overhang in the die and the tendency of the metal to flow too rapidly. The factors determining whether a shell can be produced by ordinary methods without wrinkling are discussed.—M. A. K.

Extruded Engine-Rings. P. V. Brown. (*Aircraft Prod.*, 1954, **16**, Mar., 106–110). The use of the Ugine Séjournet process for the extrusion of heat-resisting steels and alloys into rings for use in aircraft gas turbines is described. Details of the equipment used and the practice adopted are given.

The Principles of Deep Drawing. B. Wassilieff. (*Mét.*

Constr. Mécan., 1954, **86**, Mar., 185–191). The practical operations of deep drawing sheetmetals are considered and the limits within which metals can be deep drawn are discussed. The relationship between the original sheet size and the dimensions of the final shape is explained with examples to show how the operation must be carried out in a number of stages if the deep drawing is very severe.—B. G. B.

Practical Measurement of Wire Temperature on Multiple Wire-Drawing Machines. A. Zastera. (*Stahl u. Eisen*, 1954, **74**, Apr. 8, 461–464). A convenient temperature measuring head is described. It consists essentially of a block of insulating material carrying two notched steel bolts, arranged so that they can be held on the running wire and rapidly attain the temperature of the wire. The notches are lubricated so that heat is not generated by friction. Between the two notches is placed an iron-constantan thermocouple and this indicates the temperature of the bolts and thus the temperature of the wire. Comparison of the indicated temperature with that given by a contact thermocouple showed that the instrument is satisfactory.—J. P.

ROLLING-MILL PRACTICE

Roll Neck Bearings and Other Machine Elements Made of Moulded Synthetic Resin Compounds. W. Hensky. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 552–560). The life of plastic roll-neck bearings depends on the synthetic resin itself and on working conditions. Modern designs of bearing generally satisfy the increased requirements of higher output and quality. The life, low installation costs, and simple maintenance of these bearings make them equal and in some cases even superior to conventional bearings. Slight modification of existing plastic bearings can appreciably lengthen their life.—J. P.

Cooling Beds for Small Bar Mills. Marchais. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (12), 1943–1953). The mechanization of the processes of shearing, cooling, and straightening after rolling is discussed. Automatic cooling gives high quality and large output with reduced labour, but more mechanical and electrical equipment has to be provided and maintained.—A. G.

Contribution to the Study of the Modernization of a Medium Gauge Sheet Mill. Petitjean. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (10), 1607–1616). In spite of new continuous trains, the older medium trains are not yet obsolete because of the large variety of sections on the market. Possible improvements in the location of heating furnaces, the auxiliary equipment of trains and the processes of finishing are described. Several plans of proposed layouts are included.—A. G.

The Sheffield Experimental Cold Rolling Mill. H. Ford. (*Schweiz. Arch., Wiss. Techn.*, 1953, **19**, Nov., 323–329). [In English]. The author describes the experimental work carried out on cold rolling steel sheet in the Sheffield University mill.—H. R. M.

Investigations of the Effects of Rolling Speed on Roll Pressure, Mechanical Properties and Strip Thickness in the Cold Rolling of Steel Strip. J. Billigmann and A. Pomp. (*Stahl u. Eisen*, 1954, **74**, Apr. 8, 441–461). Unalloyed strip steel, 0·1–0·01 in. thick, has been rolled at speeds from 16 to 1460 ft./min. at various reductions, with dry and with lubricated rolls. When rolling dry, the roll pressure remains approximately constant or decreases slightly at rolling speed of up to 160 ft./min. and then increases by approx. 20% at the highest speed. With lubricated rolls, the opposite behaviour is found. The roll pressure decreases rapidly at first and then more slowly. The decrease is more rapid, the thinner the strip (h) in relation to the radius of the work rolls (R) and the greater the reduction of thickness, though the speed effect comes into play only when h/R is below a critical value. This limit depends on the reduction per pass and the surface condition of the rolls. Previous cold deformation, chemical composition and steelmaking practice have no influence on the speed-dependent change of roll pressure. Strip thickness changes with rolling speed, under otherwise constant conditions, in the same sense as the roll pressure and depends on the elastic deformation of the mill housing and on roll flattening. No effect of speed on the mechanical properties could be detected. It is concluded that change of deformation resistance during rolling or by heating of the strip is not effective since these act in opposite directions and thus cancel out. The speed effect is more likely to be caused mainly by a change of friction between rolls and strip. With dry rolls, there is an oxidation and an increase in the coefficient of friction. With lubricated rolls, the coefficient becomes smaller with increasing speed in the mixed lubrication range and then increases somewhat only in the range of fluid friction. The effect of rolling speed on roll pressure and strip thickness can be reduced but not entirely eliminated by the use of conventional lubricants. Variation in thickness must be eliminated by change of roll setting or strip tension.—J. P.

The Manufacture of Heavy Plate in the United States. W. Janssen. (*Stahl u. Eisen*, 1954, **74**, May 6, 604–618). The market and uses for heavy steel plates in the U.S.A. are discussed in relation to the development of plate rolling. The types of equipment now in use, the heating and conditioning of slabs, and the after-treatment of the plates are described. Suggestions for European practice and conditions are given, among which is the reduction of rolling programmes.—J. P.

Electrical Plant for the Metal Industries. (*Metallurgia*, 1954, **49**, Mar., 127–133). Electrical equipment installed or being constructed for the iron and steel industry by the British Thomson-Houston Co., the English Electric Co., the General Electric Co. and the Metropolitan-Vickers Electrical Co. during 1953 is described. The equipment includes rolling-mill drives, electric furnaces, mercury-arc rectifiers, and welding plant.—B. G. B.

Take the Strain Out of Slab Grinding. (*Steel*, 1954, **134**, Mar. 29, 115–116). An installation of a new type of grinding machine is described; it removes the rolled-in scale and imperfections from slabs of stainless or special steels before finish rolling. The electrically driven grinding wheels are hydraulically controlled, and are an improvement on the manually operated swing grinders previously used.—D. L. C. P.

MACHINERY FOR IRON AND STEEL PLANT

Conveyors and Elevators. H. L. Strube. (*Chem. Eng.*, 1954, **61**, Apr., 195–210). Material conveyors are classified, described, and their characteristics given. Data are included to allow the assessment of the suitability of each type for a variety of materials.—D. L. C. P.

Trackless Conveyors in Iron and Steel Works. H. D. Zeumer. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 561–568). A variety of mobile conveyors are described and illustrated. They include special trucks for the transport of ore and scrap, shovel loaders for slag, coke and for track cleaning, fork lifters and pilers for refractory bricks, tippers for scrap, heavy mandrel lifters for hot and cold rolled coils, portal cars and side pilers, and trackless travelling cranes. Some factors to be borne in mind when considering the use of such conveyors are discussed.—J. P.

Monorail Tunnel Type Machines for Shot-Peening. G. Guidicelli. (*Mét. Constr. Mécan.*, 1954, **86**, Apr., 299–301). The use of this type of machine is described and details of their operation and construction are given.—B. G. B.

Modern Developments in D.C. Crane Control Gear. J. G. F. Derrington. (*G.E.C. J.*, 1954, **21**, Apr., 99–105). The author discusses the problems which face the designer of electrical equipment for overhead travelling cranes and explains how these are usually best met by using a D.C. supply and series wound driving motors. The advantages of this type of motor, the methods of affording precise control, and the importance of proper safety devices are dealt with fully.—L. E. W.

PROTECTIVE COATINGS

Electrolytic Coatings on Metals. L. A. Rubio Felipe. (*Inst. Hierro Acero*, 1954, **7**, Jan.-Mar., (1), 1–13). [In Spanish]. Descriptions are given of the phenomena involved in the cathodic reduction of metals and the formation of alloys at the cathode. Polarization by concentration and Fick's law of diffusion are explained. Current theory on the formation of deposits is outlined and illustrated. The penetrating power of baths is described and the function of addition agents discussed.—C. B. L.

Thermostatic Control in Electroplating. L. Walter. (*Metal Finishing*, 1954, **52**, May, 78–81).

Review of Electroplating Plant. (Product Finishing, 1953, **6**, July, 84–89; Nov., 79–88; 1954, **7**, Feb., 84–90).

On the Theory of Chemical Polarization during the Solution and Deposition of Metals and Their Exposure to an Over-potential. W. Machu. (*Werkstoffe u. Korrosion*, 1954, **5**, Mar., 87–92).

POWDER METALLURGY

The Powder Metallurgy of Iron and Its Possible Applications in Spain. A. Bertoglio Cortella. (*Tecn. Met.*, 1953, **9**, Mar., 73–82). [In Spanish]. Some German methods of producing iron powders are discussed. Compacting and sintering are described.—R. S.

Powder Metallurgy: Its Fire and Explosion Hazards. R. W. Oxenbury. (*J. Chartered Insurance Institute*, 1954, **51**, 127–145, Reprint).

The Metallurgy of Powders. P. Compas. (*Rev. Gén. Méc.*, 1954, **38**, Apr., 119–123). Examples of the use of powder metallurgy for the fabrication of small parts in a variety of materials are given. The production of porous objects having self-lubricating properties, magnetic materials, and hard carbide parts is discussed.—B. G. B.

The Activation Energy of the Process of Sintering. G. Bockstiegel, G. Masing, and G. Zapf. (*Appl. Sci. Res.*, 1954, **4A**, (4), 284–294). [In German]. The time relationship for the increase in strength of briquettes of iron powder during sintering at temperatures below 906° C. is regarded as a simple power function. Experiments carried out on that basis are discussed and it is shown that the activation energy required for sintering iron in the alpha field agrees well with the activation energy of volume self-diffusion. A close relationship was found between the time function determined in this work and that obtained by Kuczynski in his model experiments on the sintering of metal spheres.—E. C.

Crystal Lattice Distortions and Sintering of Metal Powders. L. I. Gal'perina, Ya. E. Geguzin, N. Ya. Pines, and I. V. Smushkov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **88**, (2), 265–268). The relief of stresses and lattice distortions during the sintering of briquetted metallic powders (copper, iron, and nickel) was studied by X-ray investigations and measurements of the heat capacity of specimens. From the experimental data the activation energy of the relief of microstresses was determined. It was found that microstresses have no practical influence on the sintering process, since the major part of the latent energy is released before the sintering temperature is reached. The decrease in the activation energy of self-diffusion in compacted powder specimens indicates that some residual distortions are retained by the lattice up to high temperatures.—V. G.

PROPERTIES AND TESTS

Stress–Strain–Time Phenomena in Mechanical Testing. A. G. H. Anderson. (*U.S. Atomic Energy Commission Technical Information Service*, ORNL–114, May 26, 1952). The author discusses the theoretical principles and the concepts involved in a study of the stress–strain–time functions of metals in simple monotonic tension. Mathematical expressions relating stress with strain, time, and constant or variable strain rates are developed. Experiments on copper at 22° C. are described with details of the materials, apparatus, and methods used. The results obtained are presented and the conclusions are summarized. The critical experiments needed for the evaluation of equations involved in a study of variable strain rate phenomena are listed. (38 references).—L. E. W.

Notch-Bar Tensile Properties of Various Materials and Their Relation to the Unnotch Flow Curve and Notch Sharpness. H. Schwartzbart and W. F. Brown, jun. (*Trans. Amer. Soc. Metals*, 1954, **46**, 998–1020). The primary objectives of the investigation reported were the determination of the effects of strain-hardening characteristics and notch sharpness on notch tensile properties. Published data on two steel alloys were considered in comparison with the experimental results on non-ferrous metals. It was found that as the notch sharpness increases the true stress-strain curve is elevated and the ductility decreases. A correlation was found between the rate of strain hardening and the extent to which the ductility is reduced by the presence of a sharp notch.—D. L. C. P.

Poisson's Constant of Metals. W. Köster. (*Appl. Sci. Res.*, 1954, **4A**, (4), 329–336). [In German]. A device permitting the very accurate measurement of longitudinal dilatation and transverse contraction is described. The instrument was used to determine Poisson's constant for 12 cubic metals including iron, and the figures are examined critically in the light of published data. A similarity of Poisson's constants based on adjacent positions of metals in the Periodic System is commented upon.—E. C.

The Elastic Limit of Stainless Steel Weld Metal at Elevated Temperatures. T. Norén and B. Ramshage. (*Svetsaren*, 1953, **18**, (4), 47–48). [In Swedish]. Curves showing the elastic limit in relation to temperatures up to 400° C. are presented for a number of stainless steel weld metals of the 18/8 type (some containing molybdenum) as well as for 24/5 and 26/21 Cr–Ni and 25%-Cr steels. An 18/9 steel with 0·07% of carbon and 1% of niobium had an elastic limit of 37 kg./sq. mm. at 400° C. compared with 29 kg./sq. mm. for the same material without niobium.—R. A. R.

Improved Scale System for Stiffness Testing Machine. H. LaTour and R. S. Sutton. (*Amer. Soc. Test. Mat. Bull.*, 1954, Feb., 40–42). Bend or stiffness tests requiring simultaneous readings of load and angle may be made more accurately and with less operator fatigue by mounting a rotatable inverse-angle scale directly below the fixed load scale of machines of the Tour-Marshall design. A method of adapting this principle to Tinius Olsen stiffness testers of 6 and 50 in.-lb. capacities is illustrated and described.—B. G. B.

The Cold Brittleness of High Phosphorus Steel. V. M. Svechnikov and S. S. Golubev. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 467–472). [In Russian]. The influence of phosphorus and grain size on the cold brittleness of steel was investigated. It was found that: (1) Phosphorus in steel increases cold brittleness owing to an increase in the resistance to slip with rising temperature. (2) The presence of a fine grained ferritic-pearlitic structure leads to a high resistance to cold brittleness only if the groups of ferritic-pearlitic grains do not possess similar crystallographic orientation. (3) The fine grain structures obtained by hot mechanical working and by heat-treatment are not, in general, equal in their effect.

Grain-Boundary Properties Effecting Cleavage Fracture. J. Short and A. Muscott. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 368). [This issue].

Some Data on the Influence of Surface on the Cold Brittleness of Steel. E. M. Shevandin and E. V. Filatova. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 511–516). [In Russian]. The influence of the state of the surface on the cold brittleness of steel was studied. Strips cut from a copper clad steel tube were taken for the investigations. Bending tests were made on specimens with either the copper or the steel as the stretched surface. Some specimens were heat-treated at 850° C. The influence of the thickness of the copper layer on cold brittleness of steel was also studied. The presence of a copper layer on the surface of a steel considerably diminishes its tendency to cold brittleness during dynamic bending. Within the limits investigated, the thickness of the copper layer had no practical influence on the cold brittleness.—V. G.

The Role of Mechanical Twinning in the Brittle Failure of Iron. V. V. Sachkov and Ya. M. Pitak. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 460–466). [In Russian]. The influence of twinning on the cold brittleness of iron was studied. On the basis of the experimental evidence it is concluded that the hypothesis attributing cold brittleness of metals to twinning is incorrect. It is assumed that twins are formed at the moment of brittle failure under the influence of a high concentration of tangential stresses at the root of a rapidly developing crack.—V. G.

Hot Torsion Testing Applied to the Manufacture of Seamless Tubes. J. Dauvergne, M. Pélabon, and J. Ivernel. (*Rev. Mét.*, 1954, **51**, Apr., 254–264). The hot torsion test is mainly employed to assess the suitability of steels for the production of seamless tubes by oblique rolling. The test is described and results are given for mild and alloy steels. The capacity for torsion of the latter is greatly impeded by the presence of a two-phase ($\gamma + \delta$) structure. A study has been made of the many variables involved in the test including the metal studied, the form of test piece used, and testing conditions such as speed of rotation and temperature distribution.—A. G.

A Study of Factors Controlling Strength in the Torsion Test. R. D. Olleman, E. T. Wessel, and F. C. Hull. (*Trans. Amer. Soc. Metals*, 1954, **46**, 87–99). The factors determining the strength of a tool steel in the static torsion test were studied over a wide range of tempered hardnesses; the experimental method and results are given. Failure at low hardnesses is controlled by shear fracture strength, and at high hardnesses by tensile fracture strength. Retained austenite has a weakening effect.—D. L. C. P.

A Rigid Optical Dynamometer. V. R. Regel' and N. M. Melankholin. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 454–459). [In Russian]. A description of a rigid dynamometer

suitable for measurements of relaxation of stresses in compressed specimens is given.—V. G.

A Tension Impact Test for Sheet Metals. C. W. Muhlenbruch. (*Amer. Soc. Test. Mat. Bull.*, 1954, Feb., 43–50). Test specimens and fittings have been developed for determining the impact strength of sheet materials up to 0·125 in. thick. Full details of the preparation of the specimens and fittings are given. Data obtained on a number of steel specimens are presented and discussed.—B. G. B.

Ductility Transition of Weld Metal. W. S. Pellini and E. W. Eschbacher. (*Welding J.*, 1954, **33**, Jan., 16s–20s). The ductility transition characteristics of various types of weld metal were determined by drop weight testing and correlated to Charpy **V** and keyhole transition data. It is shown that the initiation of brittle fracture from a sharp, crack-like flaw does not require plastic deformation of the weld metal below a critical temperature, while above this temperature extensive deformation may be developed without fracture. The relative resistance to fracture initiation of weld metal and of structural sheets is compared and discussed in relation to the problem of brittle failures.—U. E.

Notch Ductility of Nodular Iron. W. S. Pellini, G. Sandoz, and H. F. Bishop. (*Trans. Amer. Soc. Metals*, 1954, **46**, 418–445). The brittle-to-plastic transition characteristics of various types of nodular irons were determined by Charpy impact tests. Notch tests were made to evaluate the significance of the data and establish comparisons with cast and rolled steels. Fully ferritized nodular irons of commercial composition are less resistant to brittle fracture than the steels. Optimum notch toughness in the irons is obtained with fully ferritized material low in silicon and phosphorus. Photographs of many tested specimens are given.—D. L. C. P.

The Formation of Cracks as a Result of Plastic Flow. A. N. Stroh. (*Proc. Roy. Soc.*, 1954, **A223**, May 6, 404–414). It is shown that a crack should form when about 1000 dislocations are piled up under stresses of the magnitude found in a cold-worked metal. The crack will have an equilibrium length, but this may be determined by the amount of plastic flow occurring round its tip. (14 references).—K. E. J.

The Non-Elastic Bending of Prismatic Bars. M. Broszko. (*Bulletin de l'Académie Polonaise des Sciences*, 1953, **1**, (3), 71–74). [In German]. Test data obtained when bending prismatic bars are not in agreement with von Kármán's formula because this formula is based on incorrect assumptions; a new equation is derived.—R. A. R.

The Bending of a Bar Subjected to a Changing Load. F. Szelagowski. (*Bulletin de l'Académie Polonaise des Sciences*, 1954, **2**, (1), 37–39). [In German]. An equation is derived for determining a force applied to the upper end of a vertical prismatic bar which will be sufficient to bend the bar when it is already subjected to a constant load over its whole length.

The Dimensional Effect in Plastic Materials. N. G. Plekhanova and S. I. Ratner. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 445–453). [In Russian]. It was found experimentally that the resistance to initial plastic deformation and the rupture characteristics of plastic structural materials depend on the dimensions of the test pieces. The dimensional effect in relation to the limit of proportionality and yield point of highly annealed structural steels is mainly of a statistical nature and is conditioned by the unequal initial resistance to plastic deformation of small volumes of the metal. It was shown that the increase in the limit of proportionality and yield point of highly plastic pure metals with the decrease in specimen diameter is due to the surface hardening caused by mechanical working (machining). Under severe machining conditions this effect can also appear in steels. With increasing specimen diameter the resistance to destruction and the plasticity are diminished. This influence of dimensions on the two values can be explained by the fact that with an increase in diameter, perpendicular stresses play a more important rôle in failure.—V. G.

A Photo-Elastic Study of Stresses in Screw Threads. A. F. C. Brown and V. M. Hickson. (*Proc. Inst. Mech. Eng.*, 1952–53, **1B**, (12), 605–620).

Plane Plasticity. B. B. Hundy. (*Metallurgia*, 1954, **49**, Mar., 109–118). The fundamentals of the theory of plasticity are presented as a basis for the understanding of the more useful parts of the theory. The second part of the paper is devoted to experimental work and checking a number of theoretical predictions of deformation behaviour. Excellent agreement between theory and practice is obtained in nearly all cases.—B. G. B.

Proceedings of the Second International Congress on Rheology. V. G. W. Harrison. [Editor]. (Butterworths Scientific Publications, 1954). The Second International Congress on Rheology at Oxford on July 26–31, 1953, was attended by some 245 members from 15 countries with about 50 guests. The papers with discussions are presented in this 451-page volume. The papers on the flow of metals are:

Creep of Metals under Pulses of Constant Stress. A. J. Kennedy. (260–265).

On the Transient Flow of Metals at High Temperatures. P. Feltham. (267–273).

Observations on 'Plastic' and 'Elastic' Hardness. P. Grodzinski. (303–309).

The Attenuation of Damped Free Vibrations and the Derivation of the Damping Law from Recorded Data. K. Klotter. (*Stanford University, Division of Engineering Mechanics, Tech. Report No.* 23, Nov. 1, 1953).

On the Nature of Viscous Destruction of Metals. V. A. Pavlov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **91**, 253–255, National Science Foundation Translation No. 100, Oct., 1953). Changes in the properties of metal undergoing plastic deformation were studied on steel specimens by determining the relation between the impact strength and the magnitude of the preliminary plastic tensile deformation. Experimental results lead to the conclusion that this dependence reflects the effect of plastic deformation, not on brittle, but on viscous destruction. It is proposed that the instant that necking commences be taken as the beginning of viscous destruction.

Damage to Steam Drums and Pipelines. K. Baatz. (*B.W.K.*, 1954, **6**, May, 177–179). Several types of damage found to have occurred in plant operating with superheated steam are described, their causes are traced, and methods for their prevention are outlined.—P. F.

Examination of Boiler Tubes. A. H. da Silveira Feijó, M. Carolina da Silva, H. Lodewijk Radino, E. Goulart de Andrade. (*Rev. Quím. Ind.*, 1953, **22**, Dec., 12–21). [In Portuguese]. A report is given of the cause (local overheating) of failure of boiler tubes, from a ship, made of steel with 0·5% Mn, under 0·1% Ni and 0·08–0·18% C. The evidence of numerous macro- and micrographs is discussed.—C. B. L.

Fatigue Testing Applied to Assemblies and Structures. H. de Leiris. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, July, 203–211). [In French]. The difficulties associated with fatigue testing of complete assemblies or structures are illustrated by examples. They include the difficulty of knowing what load is actually being applied to the structure and also the lack of knowledge of the distribution of loads within the structure.—H. R. M.

Critical Study of the Prot Method for the Measurement of Fatigue. A. P. Boresi and T. J. Dolan. (*Rev. Gén. Méc.*, 1954, **38**, Feb., 55–60). The classical method of measuring fatigue is compared with the Prot method which permits a reduction in the time of testing. Details of the Prot test procedure are given, and some results obtained with Armco iron specimens are discussed. These results are compared with those obtained by the classical method. The theory of the Prot method and a method of deriving certain constants used in the calculation are also explained.—B. G. B.

Shot-Peening in Engineering. A. Oreffice. (*Mét. Constr. Mécan.*, 1954, **86**, Apr., 291–297). The use of shot peening to improve the properties of steel parts is considered. The Straub, Valentine and Fax-film methods of examining shot-peened surfaces are described. Examples are given of the large increase in fatigue strength of steel parts after shot-peening and the effect of nickel and chromium coatings combined with shot-peening on fatigue strength is discussed. The improvement in the resistance to corrosion of stainless steels after shot peening is also considered.—B. G. B.

Fatigue in Ship Structures. R. Weck. (*Trans. Inst. Naval Architects*, 1953, **95**, 305–327). Having discussed fatigue failure in redundant and non-redundant structures, the author explains the different forms which fatigue failures will take in riveted and in welded ships. Tests are then reported the object of which was to determine: (*a*) The effect on fatigue endurance of different types of joint between plating and stiffeners; and (*b*) the effect on fatigue endurance of different types of joints in stiffeners. The specimens consisted of low-carbon steel plates 10 ft. × 2 ft. × $\frac{5}{16}$ in. stiffened in the 10 ft. direction by two 6 × 3 in. angles. They were tested

in bending by the resonance vibration method. The test data showed that continuous welds are much better from the fatigue point of view than intermittent welds, but the increased cost of replacing all intermitten welds by continuous welding could not be justified. In general, the fatigue strength of butt welds reinforced by straps was reduced by the welded straps. Scalloped stiffeners attached by intermittent chain welding did not show up very favourably in this investigation.

The Dependence of the Influence of Single and Multiple Stress Raisers on the Degree of Cyclic Overloading. L. M. Shkol'nik. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 517–526). [In Russian]. An investigation of the dependence of the influence of stress raisers on the degree of cyclic overloading made with specimens of open-hearth and converter steels in the cast, forged, and rolled state are described. The experimental results are discussed.—V. G.

The Plastic Fatigue Strength of Pressure Vessel Steels. J. H. Gross, D. E. Gucer, and R. D. Stout. (*Welding J.*, 1954, **33**, Jan., 31s–39s). The plastic fatigue properties of a high-tensile steel and a carbon pressure-vessel steel have been compared. Strain, surface preparation, testing temperature, welding, and heat-treatments are discussed.—U. E.

The Resistance to Fatigue of Chromium Steels. P. Morisset. (*Rev. Gén. Méc.*, 1954, **38**, Feb., 61–65; Mar., 99–102). A detailed examination of the fatigue resistance of steels plated with chromium is made. The fatigue resistance of a number of steels from different sources in the plated and unplated condition are presented in tabular form. The influence of the hardness, preliminary mechanical or thermal treatment, shot peening, nitriding and pickling of the base metal on fatigue resistance, is examined. The effect of the hydrogen content, conditions of electrolysis, thickness, and thermal treatment of the chromium plating on the fatigue resistance is considered. The practical application of these results is discussed. (18 references).—B. G. B.

Problems in the Standardization of Hardness Testing. E. Kruse. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, Oct., 295–299). Difficulties in the way of achieving a universal hardness test for all materials are: Differences in definition of hardness; lack of linearity in existing hardness scales; and the fact that tests may measure elastic plastic, or total hardness. It is important to be clear what properties the test is intended to measure, and the following three types of test are suggested: (*a*) For materials having high elasticity, measurement of the impression after removing the load gives a measure of flow limit or tensile strength; (*b*) for materials with low elasticity, measurement during application of the load gives a measure of elastic modulus; and (*c*) for materials of low viscosity, measurements after both short and long durations of loading give a measure of viscosity.—H. R. M.

Microhardness Testing in Theory and Practice. E. M. Onitsch-Modl. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, Nov., 330–343). The theoretical basis of microhardness testing and the relation between hardness value and load are shown to be essentially the same as for normal indentation hardness testing. The field of usefulness of microhardness testing, for measuring hardness under conditions where ordinary indentation tests cannot be applied and for following structural changes, is illustrated by examples.—H. R. M.

Change of Hardness and Toughness of Several Tool Steels by Tempering. K. Deguchi and R. Suga. (*Tetsu to Hagane*, 1951, **37**, Dec., 653–660). [In Japanese]. Results are presented of impact-tension values, bending strength, and deformation energy, after tempering at various temperatures for carbon, 1% Cr, Cr–W, Cr–W–V, and high-speed steels.—K. E. J.

Delayed Failure of Hardened Steel. S. S. Shurakov. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 527–536). [In Russian]. The phenomena of the lowering of strength of a hardened steel under the influence of static load was investigated. This phenomena is explained by the processes of plastic deformation taking place in the individual favourably orientated grains, under stresses lower than those of the 'short-term' strength. It was found that the development of plastic deformation leads, in time, to overstressing and failure of the boundaries of the initial austenite grains.—V. G.

The Determination of the Mechanical Properties of Metals Using a Small Conical Impression and a Shallow Scratch. F. F. Vitman, N. A. Zlatin, V. A. Stepanov, and L. M. Shestopalov. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 388–399). [In Russian]. A critical survey of literature on the determination of mechanical properties of metals without taking specimens is given. In experiments with a number of metals, including iron and steel, it was found that with a small conical impression and a short shallow scratch, several properties of metals such as yield point and tensile strength can be determined. (45 references).—V. G.

The Determination of the Mechanical Properties of Metals Using a Small Conical Impression and a Shallow Scratch at Elevated Temperatures. F. F. Vitman, N. A. Zlatin, B. S. Ioffe, and L. M. Shestopsalov. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 549–559). [In Russian]. The apparatus for determining the mechanical properties of metals at elevated temperatures in vacuum without preparing specimens, is described. The practical possibility of determining the yield point and tensile strength at elevated temperatures using a small conical impression is demonstrated.—V. G.

The Continued Influence of Residual Stresses on the Fatigue Strength of Steel Parts After Long Storage. I. V. Kudryavtsev and N. N. Savvina. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 412–416). [In Russian]. An attempt was made to follow the change in fatigue strength after storage up to two years of steel specimens with or without stress concentrations in the form of half-round notches. The residual compressive stresses in specimens were obtained by work hardening during rolling. It is concluded that prolonged storage (12–24 months) does not decrease the fatigue strength of steel parts.—V. G.

The Influence of Work Hardening and Ageing on the Damping Capacity of Low Carbon Steels. L. A. Glikman and E. A. Khein. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (3), 400–411). [In Russian]. The influence of work hardening (by stretching with from 2 to 12·5% elongation) and subsequent heating in the temperature range 100–650° C. on the relation between change in damping and the stress amplitude was studied. It was shown that: (1) Work hardening increases damping in the region of small stress amplitudes and diminishes in the region of larger ones in comparison with an annealed metal. (2) Ageing after work hardening sharply decreases damping over the whole range of amplitudes. (3) During the heating of work hardened specimens, a slow restoration of damping can be observed; at 650° C. the damping values are restored to the initial state. (4) The dependence of damping on the amplitude of vibrations was observed for both work hardened and work hardened and aged metals. (5) The results obtained support the view that damping is conditioned by two processes: diffusion and local plastic deformation.—V. G.

Contribution to the Study of Anomalies of Internal Friction in α-Iron Due to the Presence of Carbon and Nitrogen in Solution. L. Guillet and B. Hocheid. (*Compt. Rend.*, 1954, **238**, Feb. 22, 905–906). Small amounts of carbon or nitrogen in α-iron lead to a maximum in the damping effect at a temperature which is a function of the frequency of vibrations and the content of impurities. The maximum due to nitrogen occurs at a lower temperature than that caused by carbon. The results obtained give activation energies for the diffusion of carbon and nitrogen of 20,100 cal./mol. and 18,600 cal./mol. respectively.—A. G.

How Cold Work, Heat Treat Change Properties of 18-8 Wire. S. Storchheim. (*Iron Age*, 1954, **173**, Feb. 18, 146–148). Experiments to determine the effects of cold reduction and heat-treatment on the transformation of austenite to martensite are described. This transformation provides marked differences in electrical properties; magnetic measurements were made by projecting the hysteresis loop of the wire upon the screen of an oscilloscope. Plots of coercive force and remanence against reduction of area are given for various heat-treatments.—A. M. F.

Modern Permanent Magnets and Their New Application in Engineering Industries. R. Chouteau and R. Meyer. (*Rev. Gén. Méc.*, 1954, **38**, Mar., 86–91; Apr., 125–129). The magnetic and mechanical properties of a number of modern permanent magnets, their method of manufacture and use are presented in tabular form. The application of these new materials is discussed and examples of their use for clamping and moving objects, collecting ferromagnetic particles, and in mechanical transmissions are given.—B. G. B.

Transformer Cores with Special Properties Obtained from Silicon Steel. A. Smoliński. (*Bulletin de l'Académie Polonaise des Sciences*, 1953, **1**, (3), 109–114). [In English]. The lack of suitable vacuum furnaces in Poland led to the development of a different method of producing transformer cores from silicon steel. In this method, the silicon steel is produced in arc furnaces and then refined in hydrogen furnaces at a

temperature above 1200° C. The magnetic properties of some sheets produced in this way are given.—R. A. R.

Applications of Magnetostriction. (*Usine Nouvelle*, 1954, **9**, Jan. 21, 55–56). Of the magnetostriction effects (Joule, Villari, Nertheim, and Niedemann) the Joule effect has been applied for the generation of ultrasonics, employed for stirring, homogenization, welding, and dust precipitation. The Wertheim effect is utilized in pick-ups for sound reproduction, and that of Villari in echo sounders and the magnetostriction dynamometer.—A. G.

Experiences with Ultrasonic Reflectoscope Inspection of Main Seam Welds of Seven Large Spheres. L. Tarr. (*Amer. Soc. Test. Mat. Bull.*, 1954, Feb., 54–60). The use of the ultrasonic method for testing the soundness of welds in seven large spherical steel tanks is described. Radiographs and trepanned samples were also taken from three tanks and good agreement was found between the three methods so that the ultrasonic method was used alone to determine the soundness of the welds in the other four tanks.—B. G. B.

Investigations on Test Specimens with Known Defects for Defining the Working Conditions for Ultrasonic Testing. E. Theis and K. Barteld. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 159–164). Ultrasonic tests on specimens of different shapes and with various artificial defects and surface finishes have shown that it is possible to estimate the size of a defect from the ratio of defect and terminal echoes, and the ratio of the distances to the defect and the back wall, provided that the following precautions are observed: A defect must be examined from several directions and a constant receiver sensitivity employed. The quartz head must make good contact with the material being tested. The back wall must be parallel to the front wall. In testing cylindrical bodies the estimation of defect size depends on experience. In spite of the elimination of many disturbing influences, it is still a difficult task to get a good estimate of defect size, though a skilled operator can, by comparison with the effects of known defects, make a close estimation of the most probable size of defects.—J. P.

X-Ray Stress Measurement and Examples of Its Use. A. Schaal. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, July, 211–217). The fundamental principles of stress measurement by X-rays are dealt with, with special reference to the various types of Debye-Scherrer lines occurring in practice and the accuracy of measurement associated with them. Means of determining by visual examination whether stresses are tensile or compressive, high or low, are described, and examples show the types of problem for which the method is particularly suitable.

Development of New Alloy Constructional Steels. H. Jenny. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18**, Dec., 405–412). The paper deals with recent developments of heat-treating and case-hardening steels with carbon content up to 0·6% and total alloy content up to 5%. Owing to shortage of nickel and molybdenum, development in Europe has been in the direction of replacing some of the nickel by chromium. The mechanical properties of the new Ni–Cr and Ni–Cr–Mo steels are compared with those of the steels with higher nickel content, with particular regard to the thickness of section.—H. R. M.

Effect of Composition on Transverse Mechanical Properties of Steel. C. Wells, J. V. Russell, and S. W. Poole. (*Trans. Amer. Soc. Metals*, 1954, **46**, 129–156). The results of an investigation of the effects of changes of composition on tensile strength, transverse impact quality of certain normalized, quenched, and tempered steels are presented and discussed. The composition of a series of ingots was modified by ingot mould additions of carbon, silicon, nickel, chromium, molybdenum, boron, and rare earths. The effect of varying quantities of these elements is given for a range of temperatures by curves, and these effects are summarized.—D. L. C. P.

Effect of Carbon and Boron on the Hardenability of a Case-Carburized Steel. R. A. Grange and J. B. Mitchell. (*Trans. Amer. Soc. Metals*, 1954, **46**, 446–482). A matched pair of 2%-Mn steels, one with and one without boron, were carburized and their hardenability measured throughout the case and in the core by the end-quench method. The data are analysed to show the effect of carbon and boron upon hardenability of the carburized case. Boron had a greater effect in the core and diminished with increasing carbon throughout the case. The larger the percentage of martensite the greater was the apparent hardenability effect of boron.

Boron in Case-Hardening and Heat-Treatable Steels. E. Theis. (*Stahl u. Eisen*, 1954, **74**, Mar. 25, 412–418; May 6, 655–660). This review of the literature deals mainly with recent practice in the full-scale manufacture and processing of commercial boron steels, and the manner in which boron improves certain properties.—R. A. R.

The Origin of Shell-Like Fractures in Nickel–Vanadium Steels. Z. Eminger. (*Hutnické Listy*, 1954, **9**, (4), 203–218). [In Czech]. Results of laboratory experiments involving the study of about 1400 shell-like fractures show that: (1) The tendency to such fractures is enhanced by deoxidation and low sulphur content; (2) the nature and distribution of the "shells" in fracture surfaces depends upon solidification conditions; (3) it can be influenced by suitable heat-treatment; (4) a direct relation between the mechanical properties of the steels and the tendency to show these fractures does not appear to exist; (5) suitable methods of forging and associated heat-treatment can eliminate the "shells," so that only ordinary crystalline fractures are obtained; and (6) these fractures are characteristic of steels which are known to be liable to hot tearing. A statistical study of the influence of composition and gases in the steels was made.—P. F.

Segregation Phenomena in a Chromium–Nickel Steel with 4·5% of Nickel. W. Jellinghaus. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 165–167). In continuation of previous work by Janssen, Houdremont, and Jellinghaus (*see J. Iron Steel Inst.*, 1954, **176**, Feb., 242) artificial segregation was produced in a 0·15%-C 1·1%-Cr 4·6%-Ni steel by heat-treatment in the range 620–690° C. and detected by magneto-thermal and microscopical methods. The segregation after treatment at 690° C. showed itself by an increase in the tensile strength and hardness, and a decrease in the yield stress and impact strength. After hardening and tempering, the mechanical properties of segregated and non-segregated materials were much the same.—J. P.

Manufacture of Special Steels in France. A. Michel. (*Tecn. Met.*, 1953, **9**, Sept., 293–300). [In Spanish]. The author first defines the French conception of "special" and "quality" steels. He explains why French steelmakers have opposed the introduction of the fatigue test as an acceptance test in their national standards. The efficacy of mechanical tests and chemical composition specifications is evaluated.—R. S.

Surface Defects of Springs—Their Causes and Remedies. V. M. Ayuela Berjano. (*Tecn. Met.*, 1953, **9**, Jan., 1–17). [In Spanish]. The behaviour of steels from the point of view of surface decarburization and the influence of the state of the surface on hardening and tempering are discussed. Results of fatigue tests are correlated with surface properties of springs. The effect of internal stresses in the surface zones on fatigue properties are studied. Finally, the influence exerted by high temperatures on springs having protective coatings against corrosion is reviewed.—R. S.

Some Metallurgical Variables Affecting Quench Cracking Susceptibility of Hollow Alloy Steel Cylinders. C. F. Sawyer and C. C. Busby. (*Trans. Amer. Soc. Metals*, 1954, **46**, 100–112). The effect of several metallurgical variables on the quench cracking of hollow cylinders (which are subsequently converted into gun tubes) has been studied and the results are reported. A laboratory test involving quenching discs in a special jig was used, and the results corresponded with production experience.—D. L. C. P.

Proposed Classification of Mild Steel, Taking into Account Its Tendency towards Brittle Fracture. G. Malmberg. (*Jernkontorets Ann.*, 1954, **138**, (6), 333–349). [In Swedish]. Based on a series of investigations of mild steels suitable for welding, a tentative test standard has been evolved which takes into account the risk of brittle fracture. A study of the Charpy test specimen shows that the critical impact test reading is 3 kgm./sq. cm., so that specimens exceeding this value can be classed as tough. In the suggested standard this value is changed to 3·5 kgm./sq. cm. and, using this as a starting point, welding steels in the tensile range 35–55 kg./sq. mm. are divided into four groups dependent on their application. Test temperatures of 0, − 20, and − 40° C. have also been proposed.—G. G. K.

Determination of the Surface Tension of Cast Irons and Pig Irons. K. Grütter and B. Marincek. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, June, 171–173). The surface tension of grey cast irons, spheroidal graphite cast irons, a foundry pig iron, and hematite pig irons from blast-furnaces and from electric low-shaft furnaces, were determined. The values, in general,

were in the range 800–1100 dynes/cm., decreasing slowly with increasing temperature, but the spheroidal graphite cast irons had surface tensions of 1300–1400 dynes/cm.—H. R. M.

Qualities and Applications of High-Grade Cast Iron. J. Sissener and C. Woxholt. (*Jernindustri*, 1954, **35**, (2), 29–38). [In Norwegian]. A review of recent developments in high-grade cast irons deals with specifications for tensile strength, characteristics of Meehanite, alloy additives and their effects, nodular cast iron, advantages of electric melting, typical design improvements, and use of cast iron for gear wheels and crank shafts.—G. G. K.

METALLOGRAPHY

A Polarizing Apparatus for Microphotography and for Projection of Microscopic Slides. P. Ljunggren and S. Dahlén. (*Geol. Föreningens Förh.*, 1954, **76**, Mar.-Apr., 337–338). [In English]. Constructed to take large microphotographs in polarized light, the apparatus is based upon two polarizing plates, one of which is fixed while the other is hinged so that it can be swung through 100°. The slide is mounted and held in place by a spring. When placed between the polarizing plates, the whole mounting can be swung through 180°. Provided that a high-quality enlarger objective is used (Leica), good photographs can be taken of the whole of the slides. With a slight change, the apparatus can be inserted into the projector in place of the slide-holder.—G. G. K.

The Proton Microscope. (*Usine Nouvelle*, 1954, **9**, Feb. 4, 25–27). In principle this instrument is an electron microscope utilizing ions instead of electrons. Details of its construction are given. Great accuracy of assembly is necessary if a resolving power of 3Å is to be approached.—A. G.

The Flying-Spot Microscope. F. Roberts and J. Z. Young. (*Proc. Inst. Elec. Eng.*, 1952, **99**, Part IIIA, No. 20; Paper No. 1348, Radio Section). A cathode-ray tube providing a television raster of high brilliance and short time-constant is placed in front of the eyepiece of a microscope. The objective produces a minute spot of light that scans the preparation under examination. The amount of light transmitted is determined by the density of the specimen, and the transmitted light is picked up by a multiplier photocell, the output of which is used to modulate a display cathode-ray tube, the raster of which is locked to the scanning raster. Pictures superior to those of a normal optical microscope in size, brightness, contrast, and resolution of low contrast materials are obtained. Applications described include some in nuclear physics and chemical engineering.—R. A. R.

Symposium on Techniques for Electron Metallography. (*ASTM Spec. Techn. Pub. No.* 155, 1954, 1–144). This Symposium, sponsored by ASTM Committee E-4 on Metallography, was held at Atlantic City on June 30, 1953. The papers presented were:

Techniques Used in Electron Microscopy of Aluminium Alloys. M. S. Hunter and F. Keller. (3–14).

Techniques for the Study of Precipitated Carbies. (15–32).

Inorganic Replication: Interpretation of Electron Micrographs. C. J. Calbick. (33–48).

Electron Microstructure of Steel by " Extraction Replica " Technique. R. M. Fisher. (49–64).

Metal Shadowing for Contrast Enhancement—Comparison of Shadow Metal and Shadow Angle. D. M. Teague. (65–82).

Specimen Polishing Techniques for Electron Metallography of Steel. W. L. Grube and S. R. Rouze. (83–95).

Techniques that Permit Successive Examinations of Specific Areas by Electron Microscopy. T. A. McLauchlan. (96–109).

Replica Washing Methods. E. F. Fullam. (101–108).

Application of New Etchants for Delineation of Fine Structure in Steel. (109–118).

Techniques for Ferrous Electron Metallography. Subcommittee XI of Committee E-4. (119–144). This progress report presents the results of a study of the structures of specimens of eutectoid steels.

Examination of Metal Surfaces with the Electron Microscope and by Electron Diffraction. K. Huber. (*Met. Ital.*, 1954, **46**, Feb., 41–48). The author discusses the scope which electronic rays provide for studying metal surfaces. The advantages are stressed of combining the electron diffraction method (by flat angle incidence and transparency of isolated layers) and the replica method. This combination of techniques provides a means of drawing the most detailed conclusions on the composition and structure of metal surfaces.—M. D. J. B.

Phase-Contrast Microscopy in Metallography and Mineralogy. R. Mitsche. (*Met. Ital.*, 1954, **46**, Mar., 79–84). The phase-contrast method which is described provides a useful auxiliary means of studying non-transparent substances with an optical microscope. The method can be used in metallography, mineralogy, and for studying coals.—M. D. J. B.

A Pressurized High-Temperature Debye-Scherrer Camera, and Its Use to Determine the Structures and Coefficients of Expansion of γ- and δ-Manganese. Z. S. Basinski and J. W. Christian. (*Proc. Roy. Soc.*, 1954, **A223**, 20 May, 554–560). With a new camera the structures of γ- and δ-manganese were found to be face- and body-centred cubic respectively. Lattice-spacing and expansion data are given for these, and for β-manganese.—K. E. J.

Study of the Hexagonal Carbonitride of Iron (Fe_3N Type). R. Bridelle and A. Michel. (*Rev. Mét.*, 1954, **51**, Apr., 278–282). A description is given of various methods devised for the preparation of hexagonal Fe-C-N phases of the type Fe_3N. A structural and thermomagnetic study reveals that the lattice parameters and Curie point vary widely with the carbon and nitrogen contents. These phases are only stable below 450° C.—A. G.

The Size of the Secondary Austenitic Grains in Steels with Aluminium Additions. D. S. Kamenetskaya and I. B. Piletskaya. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (1), 60–66). [In Russian]. The influence of aluminium additions on the size of secondary austenite grains was investigated. Aluminium dissolved in steel promotes, during heating, the formation of nuclei of secondary austenite and inhibits grain growth. The experimental results on the influence of aluminium suggest that it decreases the boundary and surface energies and increases the activation energy during the phase transformation.—V. G.

The Angular-Appearing Carbides in High-Speed Tool Steels. C. J. McHargue, J. P. Hammond, and C. S. Crouse. (*Trans. Amer. Soc. Metals*, 1954, **46**, 716–726). The angular-appearing particles present in high-speed tool steels after overheating were studied using two types of steel. The particles were found to be of the same crystal structure, and probably of similar composition (the forms M_6C and MC), as the carbides ordinarily reported for the steels.—D. L. C. P.

The Graphitization of Steel at Subcritical Temperatures. R. H. Hickley and A. G. Quarrell. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 337–346). [This issue].

On the Mechanism of the Influence of Silicon on the Graphitization of Iron Alloys. K. B. Bunin. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **95**, (1), 97–99). [In Russian]. The formation of micropores during the diffusion of silicon in Armco iron was studied. Specimens of silicon and Armco iron were pressed together and placed into a tube furnace at 1100° C. in a stream of hydrogen for 38 hr. A diffusion layer 1·8 mm. thick was obtained. Microscope investigations of this layer showed that the silicon-rich part of the ferrite contains micropores. Therefore the redistribution of silicon in solid solution in iron may lead to the formation of micropores. The influence of silicon on graphitization is explained by the formation of micropores, particularly at the contact surface of carbide with solid solution. During the process of the formation and growth, the micropores can be filled by carbon migrating from the supersaturated solid solution and from carbide, thus forming graphite nuclei.—V. G.

On the Shape of Carbon Inclusions Formed During the Heat-Treatment of Magnesium-Inoculated Cast Irons. K. P. Bunin and A. V. Chernovol. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **95**, (4), 785–787). [In Russian]. Factors influencing the form of graphite inclusions during the graphitizing heat-treatment of a magnesium-inoculated cast iron were investigated on specimens of white iron (3·03% C, 0·50% Si, 0·30% Mn, 0·09% P, 0·009% S, and with 0·047%, 0·076%, and 0·093% Mg), heat-treated at 850, 950, and 1050° C. The growth of the graphite inclusion at various stages of heat-treatment was followed by microscopical examination in polarized light. It was found that graphite nodules are only formed within the austenite phase. If a graphite inclusion is bounded on one side by a carbide grain and on the other by austenite it will only grow into the austenite, attaining the shape of an irregular polyhedron. The growth of a carbide inclusion in primary austenite is faster than in secondary austenite (formed during heat-treatment). The form and growth of

graphite inclusions is governed by the conditions of migration of iron atoms from the graphite nuclei into the matrix which in a white iron is easier along the grain boundaries. In magnesium-inoculated iron this is not important, since magnesium is concentrated at the grain boundaries where it inhibits the boundary self-diffusion of iron and this excludes the formation of graphite along the grain boundaries.—V. G.

Fractional Fusion. C. H. L. Goodman. (*Research*, 1954, **7**, May, 168–177). A series of new techniques has recently been developed for the purification and homogenization of solids. They are applicable to the small-scale purification of elements and compounds, homogenization of mixtures and preparation of single crystals.—K. E. J.

Electronographic Investigation of the Structure of Cubic Iron Nitride. Z. G. Pinsker and S. V. Kaverin. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **95**, (4), 797–799). [In Russian]. The structure of the cubic form of iron nitride (Fe_4N) was investigated. Samples were obtained by evaporating iron (Armco wire) *in vacuo* and condensing it on the face of a cube of NaCl heated to about 300° C. In this way highly orientated monocrystalline films were obtained. These were nitrided in a stream of ammonia in the temperature range 225–650° C. for 15 min. to 8 hr. Electronographic investigations of these samples showed that the nitrogen atoms are situated in the octahedral sites of the iron lattice.—V. G.

Some Aspects of the $\alpha \rightarrow \gamma$ Transformation of High-Purity Iron. P. R. Pallister. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 346–348). [This issue].

The Transformation of α-Iron to γ-Iron During Abrasion. R. P. Agarwala and H. Wilman. (*Proc. Roy. Soc.*, 1954, **A223**, Apr. 22, 167–174). Abrasion of the surface of an iron crystal by emery paper with light hand pressure caused the formation of γ-iron, indicating a rise in temperature of some 900° C. The formation is described, and a suggested mechanism of transformation involves a shear on $\{211\}\alpha$ along $< \bar{1}11 > \alpha$ as in normal $\{211\}$ twinning. (14 references).—K. E. J.

Study of Phase Transformations by an Internal Friction Method. K. M. Rozin and B. N. Finkel'shtein. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **91**, 811–812; *National Science Foundation Translation* 143, Dec., 1953). A study of phase transformations in a sample of a carbide-forming austenitic steel (0·3% C) using the method of damping torsional oscillations of wire specimens in the temperature range 20–800° C. at frequencies of the order of 1 cycle/sec. is described.—V. G.

The Relationship Between the Curves of Isothermal Austenite Transformation During Continuous Cooling. M. Kozlowski. (*Hutnik*, (*Poland*), 1954, **21**, (3), 66–72). [In Polish]. The knowledge of the dependence of the initial and end temperatures of transformation of supercooled austenite on the cooling velocity provides a means of controlling the effect of hardening, *i.e.*, the change in the mechanical and physical properties of the hardened object. The determination and application of curves of the initial transformation of supercooled austenite during continuous cooling are discussed.—V. G.

ANALYSIS

The Assessment of Individual Sources of Error in the Combustion Method for the Determining of Sulphur in Steel. I—Mild Steel. T. B. Smith, A. Backhouse, and P. Woodward. (*J. Appl. Chem.*, 1954, **4**, Feb., 75–82). Methods for the determination of individual errors have been developed which, when applied to a particular mild steel under the usual working conditions, show that at 1300° C. only about 86% of the total sulphur is liberated as sulphur dioxide. Of the other 14%, the residue retains about 6% and the rest is converted into sulphur trioxide, 3% being absorbed with the sulphur dioxide, 1% escaping absorption, and 4% remaining in the apparatus by condensation. Modifications are suggested by which the total yield could be raised to 92–93%.

Note on the Colorimetric Determination of Vanadium in Steels. R. Rosotte and E. Jaudon. (*Chim. Analy.*, 1954, **36**, June, 160–161). The reaction $V^{4+} + Fe^{3+} \rightleftarrows V^{5+} + Fe^{2+}$ has been investigated and a colorimetric method based on it evolved for analysing low-alloy steels containing small amounts of vanadium. Good sensitivity is reported with satisfactory reproducibility.—A. G.

Spectrophotometric Determination of Cobalt with 2-Nitroso-1-Napthol-4-Sulphonic Acid. W. M. Wise and W. W. Brandt. (*Analy. Chem.*, 1954, **26**, Apr., 693–697). The colouration produced by the complex cobalt (II)-2-nitroso-1-napthol-4-sulphonic acid has been shown to be stable, and to obey Boer's law between molar concentrations of 4×10^{-6} and $1{\cdot}25 \times 10^{-4}$. The effects of *p*H, reagent concentrations and interfering ions have been investigated. The method is convenient, rapid, and accurate.—A. G.

The Construction of a Combined Sources Unit for Emission Spectrography. R. G. Stone and H. L. Bolton. (*J. Sci. Instruments*, 1954, **31**, May, 175–178). The construction of a combined sources unit is described, containing a D.C. arc, a Hilger constant current D.C. arc, a Kingsbury and McClellan intermittent A.C. arc, a Walsh pulsed D.C. arc, a Brands and Clayton electronically controlled intermittent A.C. arc, and a high voltage A.C. condensed spark. Circuit diagrams and the method of construction are given.—L. D. H.

The Separation of Chromium, Manganese, Iron, and Nickel by an Ion-exchange Chromatographic Method. D. I. Ryanchikov and V. F. Osipova. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **96**, (4), 761–763). [In Russian].—V. G.

Chemical Analysis of Cast Iron. J. Buciewicz. (*Przeglad Odlewnictwa*, 1954, **4**, (4), 104–108; (5), 140–143). [In Polish]. Methods of chemical analysis for grey and white cast irons are given in the form of analytical instructions. The methods cover the determinations of silicon, manganese, phosphorus, carbon, and sulphur.—V. G.

Microscopic Identification of Wüstite in the Presence of Other Oxides of Iron. R. G. Wells. (*Analy. Chem.*, 1954, **26**, Apr., 715–717). Techniques are described which, employed with reflected light microscopy, provide a simple and accurate means of determining the types and amounts of Wüstite, hematite, and magnetite in partly reduced iron ores.—A. G.

Determination of Micro Amounts of Phosphorus in High-Purity Irons. O. R. Gates. (*Analy. Chem.*, 1954, **26**, Apr., 730–732). A method has been developed to determine down to 0·0001% phosphorus on a 4-g. sample. The bulk of the iron is separated by electrolysis with a mercury cathode, followed by further purification by precipitating the acid sulphide group. The phosphorus is determined colorimetrically by the phospho-molybdenum blue method.—A. G.

Studies on the Determination of Chromium in Iron and Steel. K. Tanino. (*J. Sci. Res. Inst.*, 1953, **47**, Dec., 258–291). When determining chromium by oxidation with $KMnO_4$ and titrating with $FeSO_4$, great care must be taken in the oxidation and the subsequent removal of the excess oxidizing agent. The results of work by a number of analysts is examined, and precautions and possible difficulties are listed.

The Quantitative Analysis of Ironstones Containing Small Amounts of Titanium, Vanadium, Manganese, Chromium, and Phosphorus. D. N. Grindley, E. H. W. J. Burden, and A. H. Zaki. (*Analyst*, 1954, **79**, Feb., 95–100). A routine method is described for the analysis of the above ores. After solution, the iron is extracted from acid solution by ether and the titanium, vanadium, and manganese are determined colorimetrically. Chromium is determined volumetrically and phosphorus gravimetrically on aliquot parts of the iron-free solution.—A. G.

Absorptiometric Determination of Molybdenum in Iron and Steel. Methods of Analysis Committee. (*J. Iron Steel Inst.*, 1954, **178**, Dec., 356–359). [This issue].

Determination of Manganese in Iron, Steel, and Ferromanganese. I. H. Gotô and S. Watanabe. (*Sci. Rep. Res. Inst. Tohoku Univ.* Series A., 1954, **6**, (1), 1–11). [In English]. The ferrous-permanganate method after oxidation with persulfate was studied. Suitable acid concentrations, boiling times, and effects of phosphoric acid were determined. An analytical procedure was established and its reliability checked on a variety of samples.—J. G. W.

ECONOMICS AND STATISTICS

Situation of Patents on the L.D.-Process Developed in Linz. E. Hochegge and K. Kafka. (*One Year LD-Oxygen Refining Process*: VÖEST, Linz-Donau, 1954, 54–56). [In English].

Standardization in the Field of Metallurgy. P. Salmon. (*Rev. Mét.*, 1954, **51**, June, 380–384). The recent revision of French National Standards to facilitate industrial reorganization schemes is discussed, together with problems confronting the International Standardization Association and the European Coal and Steel Community in the field of standardization.—A. G.

Standardization in the Iron and Steel Industry. K. Mandybur. (*Hutnik*, 1954, **21**, (5), 144–149). [In Polish]. The

importance of standardization for the industrialization of Poland and the beneficial results which can be obtained by co-ordination of Polish and Russian standards are discussed. A short survey of Polish standards is given.—V. G.

Fuel and Steel in Sweden: An Economic Survey of Problems. (*Iron Coal Trades Rev.*, 1954, **168,** May 28, 1251–1253). A brief outline is given of Sweden's natural fuel resources and some of the problems of availability and price are discussed in the light of the country's increasing fuel requirements. The influence of these problems on the development of the iron and steel industry is also considered.

Japan's Iron and Steel Industry 1953–4. S. Kawata [editor]. (*Tokyo Foreign Service*, 1954). This 208-page book, in addition to presenting production and import and export statistics, lists all the important Japanese iron and steel works and their products.—R. A. R.

MISCELLANEOUS

Department of Metallurgy at the University of Cambridge. (*Metal Treatment and Drop Forg.*, 1954, **21,** May, 215–223). A comprehensive description of the department and its facilities for teaching and research in metallurgy are given, together with a résumé of the research work in progress at the present time. This includes studies of molten metals, metallic structure and mechanical properties, fatigue, electrochemistry, and corrosion.—P. M. C.

Internal Cleaning of Boilers. J. M. Maloney. (*Indust. Eng. Chem.*, 1954, **46,** May, 983–985).

Preparation of Feed Water Make-Up. S. B. Applebaum. (*Indust. Eng. Chem.*, 1954, **46,** May, 985–988).

Deposits in Boilers. C. Jacklin. (*Indust. Eng. Chem.*, 1954, **46,** May, 989–990).

Foaming in Boilers. W. L. Denman. (*Indust. Eng. Chem.*, 1954, **46,** May, 992–994).

Present Position of the Use of Job Evaluation in the Works of the Iron and Steel Industry. H. Euler. (*Stahl u. Eisen*, 1954, **74,** June 17, 841–842). The results are displayed, in tabular form, of a series of annual enquiries to ascertain the extent to which German steel works are using job evaluation for the assessment of wages.—J. P.

Rationalization and Man Power Problems in the Iron and Steel Industry from a Physiological Viewpoint. E. H. Christensen and F. Nilsson. (*Jernkontorets Ann.*, 1954, **138,** (5), 288–309). [In Swedish]. Using relatively simple methods based on studies of oxygen intake, pulse rate, temperature, and amount of perspiration, it was possible to evaluate the physical stress in 100 jobs in the Hagfors steelworks and so establish comparative job gradings. The studies enable some sources of heat fatigue to be eliminated by suitable shielding. The results should be of importance for the placing of older or disabled workers, and in determining the work capacity of individual workers.—G. G. K.

Towards Complete Safety in Handling Operations in the Steel Industry. J. Rousseau. (*PACT*, 1953, **7,** Oct., 326–329). After an examination of the distribution of accidents in various metallurgical departments, the predominance of accidents during the handling of materials is shown. The occurrence of accidents during mineral crushing in partially and completely mechanized plants is considered.—B. G. B.

A Remarkable Achievement against Silicosis. M. Stassin. (*PACT*, 1953, **7,** June, 228–229). The treatment of mild steel ingots in a type of ball mill has been found to remove effectively the sand from the surface without the risk of danger from silicosis.—B. G. B.

The Review of Iron and Steel Literature for 1953. V. S. Polansky. (*Blast Furn. Steel Plant*, 1954, **42,** May, 537–539, 542–544; June, 675–678, 688). A list of books and pamphlets concerning the iron and steel industry published during 1953, and some of earlier date not included in the 1952 review is given.—B. G. B.

Pneumatic Tubes Speed Steel Plant Communications. A. M. Brown. (*Iron Age*, 1954, **173,** Mar. 25, 141–143). An extensive system handling bulk mail distribution, inter office communication, as well as samples from steel melting units, is described. An average of 10,000 pieces of mail are carried each day also samples of up to 5 lb.—A. M. F.

BOOK NOTICES

HOFF, HUBERT, and THEODOR DAHL. "*Walzen und Kalibrieren.*" (Stahleisen Bücher, Band 12.) 8vo, pp. x + 219, illustrated. Düsseldorf, 1954: Verlag Stahleisen m.b.H. (Price DM 22.50)

Following the authors' book on the fundamentals of rolling published in 1950, Dr. Dahl set out to write a companion volume on practical aspects of rolling; owing to his untimely death the work was completed by his former collaborator, Professor Hoff. The book deals roughly with the same topics as the standard texts on pass design by Tafel and by Trinks, but in more condensed form, particularly with regard to the principles of rolling, which were the subject of the authors' first book.

The book is divided into six chapters of which the first contains general information on rolling, rolling mills and pass design, and the middle four deal respectively with cogging, billet and plate, bar and rod, and section rolling. In each case principles of pass design are laid down, methods of calculation being illustrated by examples, and the chapters concluded with descriptions of representative plants.

The chapter on sections is confined to I-beams and channels, except for a brief discussion of rail-pass designs in the introductory section. In the concluding chapter the authors discuss briefly the results to be aimed at by good pass design, namely, the use of the smallest number of passes compatible with reasonable roll life and satisfactory product quality.

Pass design is essentially an art, *i.e.*, it admits of subjective solutions of equal merit, and therefore is a difficult subject for a technical book. In the circumstances the authors have done a good job of work not only in setting down what is generally accepted but also finding room for the statement of conflicting views, and for examples of alternative designs taken from German, English, American, and Russian literature.—J. G. WISTREICH.

JASWON, M. A. "*The Theory of Cohesion.*" An outline of the cohesive properties of electrons in atoms, molecules and crystals. Foreword by G. V. Raynor. (Pergamon Science Series, Metal Physics and Physical Metallurgy. Volume 2.) 8vo, pp. viii + 245. Illustrated. London, 1954: Pergamon Press, Ltd. (Price 37*s.* 6*d.*)

The theory of cohesion is an unoriginal, lazy, but vital, science. Unoriginal, because we are quite sure that a calculating machine, working on solutions of Schrödinger's equation, could answer all questions put to it about magnitudes of bond energies, interatomic spacings, transformation temperatures and the like. Lazy, because the theory concerns itself with finding mathematically simple approximations to stand proxy for the exact solutions, which remain unknown. Vital, because these inexact solutions are what we really want. Their various simplifications and exaggerations throw into relief certain aspects of solutions in general—*e.g.*, exchange interaction, resonance, hybridization, Brillouin zones—so striking in character that they may fairly be called the 'causes' of the various cohesive properties of matter. As Dr. Jaswon emphasizes in the book under review, a feature of the less rigorous solutions is that they split up the cohesive energy into a number of separate and identifiable components which reveal the factors controlling the cohesive process.

A natural result of all this is that many specialized techniques have been developed for deriving the most informative solutions by the least tedious routes, and a wide experience has been gained of the relative validities of the various approximations in most classes of problems. The main purpose of Dr. Jaswon's book is to explain these mathematical procedures in terms as simple as they will allow, and to show how they lead to an understanding in physical terms of the cohesive process.

The first two chapters introduce the mathematical framework of wave mechanics in a very clear manner. The author relies on a cool, precise style of writing, rather than on picturesque analogies, in order to make himself understood. Perturbation theory and variational methods are fully explained, a chapter is given to the helium atom

as a preparation for problems involving two or more electrons, and the hydrogen molecule is used as the main testing ground for evaluating the merits of rival approximations. The last three chapters deal with the theory of metals and covalent structures. The emphasis in these is on methods of obtaining binding energies, and the Wigner-Seitz approximation is discussed in great detail. Interesting views are presented on the factors determining the cohesion of alloys and of the forces round foreign atoms in metals, and some thought is given to the ways in which the plastic properties, as well as elastic properties, of crystals depend on the cohesive forces. Various mathematical points needed in the text are gathered together in a series of appendices.

As Professor Raynor points out in his Foreword, this is not a book for the general metallurgist, since it does not add to the qualitative physical picture of the metallic state which he can obtain from the many elementary treatments now available. Rather, it is for those who aim to read the original research papers and advanced monographs in this field, and who perhaps hope to do some theoretical work themselves. Such readers should find it particularly valuable, since it explains most fully and carefully the mathematical procedures which are so largely taken for granted in the research papers. Less mathematically inclined readers will be grateful for the fact that, where the metallurgical interest is greatest, as in the sections on alloys and transition metals, the mathematical content is least. It is an excellent book for all who seek a proper understanding of the solid state.—A. H. COTTRELL.

MORLEY, ARTHUR. "*Strength of Materials.*" Eleventh edition. 8vo, pp. x + 352. Illustrated. London, New York, Toronto; 1954: Longmans Green and Co. (Price 21*s.*)

The eleventh edition of this well-proved engineering textbook now completes the issue of over 100,000 copies, making it a best-seller in comparison with any popular novel. The tenth edition was published in 1952 and the issue of another edition so soon afterwards is evidence of its continued and deserving popularity.

The main change seems to be the omission, in the interests of economy, of the last three chapters of earlier editions. These dealt with the testing of metallic and other materials, and the author feels that the omission is justified in view of the increased testing facilities available in educational institutions and of the greater amount of published matter available on the subject.

It is stated in the preface to the latest edition that certain chapters or articles—for example, on creep, fatigue, and metallurgical developments of ferrous metals—have been rewritten. However, this is misleading, for the same statement appeared in the preface to the ninth edition referring to still earlier editions, and in fact, as far as the reviewer can ascertain, there has been no significant change in these directions between the tenth and eleventh editions. The need for bringing these subjects more up-to-date was mentioned by the present reviewer in respect of the tenth edition (*see J. Iron Steel Inst.*, 1953, **173**, Mar., p. 327).

A. R. BAILEY.

NEW PUBLICATIONS

BRITISH STANDARDS INSTITUTION. B.S.2496: 1954. "*Preferred Sizes of Casting Pit Refractories.*" 8vo, pp. 7. Illustrated. London, 1954: The Institution. (Price 2*s.*)

BRITISH STANDARDS INSTITUTION. "*Annual Report* 1953–4." 8vo, pp. 200. London, 1954: The Institution. (Price 5*s.*)

CABLE, J. WESLEY. "*Induction and Dielectric Heating.*" 8vo, pp. 576. Illustrated. New York, 1954: Reinhold Publishing Corp.: London: Chapman and Hall, Ltd. (Price $12.50, 100*s.*)

CAVÉ, R. "*Le Contrôle Statistique des Fabrications.*" La. 8vo, pp. 431. Illustrated. Paris, 1953: Editions Eyrolles.

EITEL, WILHELM. "*The Physical Chemistry of the Silicates.*" Pp. xvii + 1592. Illustrated. Chicago, 1954: University of Chicago Press. (Price $30). [An extended, up-to-date version in English of the author's earlier book "*Physikalische Chemie der Silicate*" (1929; second edition 1941).]

GROUPEMENT POUR L'AVANCEMENT DES MÉTHODES D'ANALYSE SPECTROGRAPHIQUE DES PRODUITS MÉTALLURGIQUES. "[16ème] *Congrès tenu les* 24, 25 *et* 26 *Juin*, 1953, *à Paris.*" La. 8vo, pp. 257. Illustrated. Paris [1954]: Laboratoire Centrale de l'Armement.

HABRAKEN, L. "*Sur la Métallographie Electronique.*" Techniques Operatoires; études des structures d'acier au carbone et d'aciers faiblement alliés; étude du comportement à chaud d'un acier au Cr–Mo. La. 8vo, pp. 163. Illustrated. Liège, 1953: Centre National de Recherches Métallurgiques (Section de Liège).

HAMPEL, CLIFFORD A. (Editor). "*Rare Metals Handbook.*" La. 8vo, pp. xiii + 657. Illustrated. New York, 1954: Reinhold Publishing Corp. (Price 96*s.*)

HARTLEY, Sir HAROLD. "*Science and Industry—The Pattern of the Future?*" The first Fawley Foundation Lecture. 8vo, pp. 24. Illustrated. Southampton, 1954: Southampton University. (Price 2*s.* 6*d.*)

"*Metal Industry Handbook and Directory* 1954." 8vo, pp. xvi + 472. London, 1954: Louis Cassier Co., Ltd. (Price 21*s.*; 21*s.* 8*d.*, post free)

MORRIS, JOE LAWRENCE. "*Welding: Processes and Procedures.*" 8vo, pp. 255. Illustrated. New York, 1954: Prentice-Hall, Inc. (Price $5)

NATIONAL BUREAU OF STANDARDS. "*Photographic Dosimetry of X- and Gamma Rays.*" National Bureau of Standards Handbook 57. 8vo, pp. iv + 28. Illustrated. Washington, D.C., 1954: Government Printing Office. (Price 15 cents)

NATIONAL BUREAU OF STANDARDS. "*Standard Samples and Reference Standards Issued by the National Bureau of Standards.*" National Bureau of Standards Circular 552. La. 4to, pp. ii + 23. Washington, D.C., 1954: Govern. ment Printing Office. (Price 25 cents)

"*Die Neuordnung der Eisen- und Stahlindustrie im Gebiet der Bundesrepublik Deutschland.*" Ein Bericht der Stahltreuhändervereinigung. 4to, pp. xxii + 870. München, Berlin, 1954: Beck. (Price DM 48.–)

ORGANISATION FOR EUROPEAN ECONOMIC CO-OPERATION. "*Corrosion Problems and Prevention in the Chemical and Petro-Chemical Industries in the U.S.A.*" Technical Assistance Mission No. 130. La. 8vo, pp. 129. Illustrated. Paris, 1954: The Organisation.

POGODIN-ALEXEJEW. "*Theorie der Schweissprozesse.*" Uebersetzung aus dem Russischen. Zweite erweiterte und überarbeitete Auflage. 8vo, pp. 496. Illustrated. Berlin, 1953: VEB Verlag Technik. (Price DM 20.–)

REBOUX, P. "*Phénomènes de Fluidisation. Documentation Générale.*" La. 8vo, pp. 165. Illustrated. Paris, 1954: Association Française de Fluidisation. (Price 1800 fr.)

RUMFORD, F. "*Chemical Engineering Materials.*" Pp. x + 380. Illustrated. London, 1954: Constable & Co. Ltd. (Price 32*s.* 6*d.*)

SÉFÉRIAN, D. "*Les Soudures. Technique—Contrôle—Soudabilité des Métaux.*" Deuxième édition. Préface de P. Chevenard. 8vo, pp. xx + 428. Illustrated. Paris, 1954: Dunod. (Price 3600 fr.)

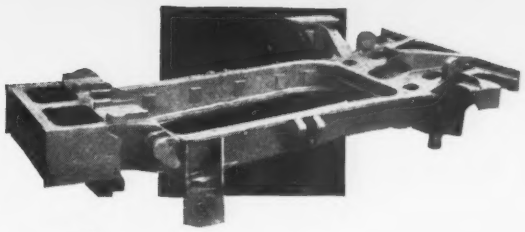
"*Thorpe's Dictionary of Applied Chemistry.*" Vol. XI. "Soil, Organic Constituents of—Zymurgy." With an index by M. Le Pla, J. G. Cockburn, and J. Burn. Fourth edition (Revised and Enlarged). 8vo, pp. x + 1145. Illustrated. London, New York, Toronto, 1954: Longmans Green & Co. (Price 140*s.*)

"*Untersuchungen über einige Probleme der Behandlung von Blechoberflächen.*" Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen Nr. 56. Hrsgeg. von L. Brandt. 8vo, pp. 41. Illustrated. Köln and Opladen, 1953: Westdeutscher Verlag. (Price (als Ms. gedruckt) DM 11.20)

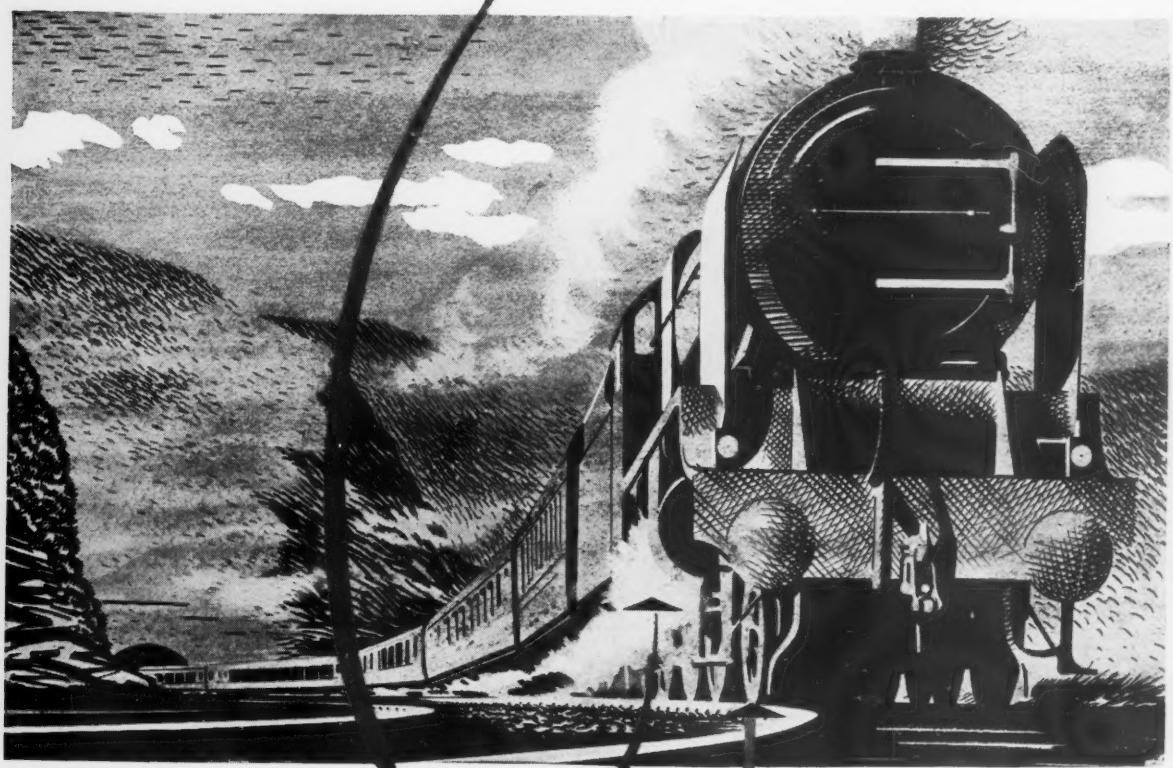
"*Zavod za Raziskavo Materiala in Konstrukcij Njegov Obseg in Delo.*" [The Institute for Testing Structural Materials, Its Equipment and Work.] La. 8vo, pp. 38. Illustrated. Ljublana, Yugoslavia, 1953: The Institute for Testing Structural Materials.

Cast for an important part . . .

Consider the strength of a Railway engine

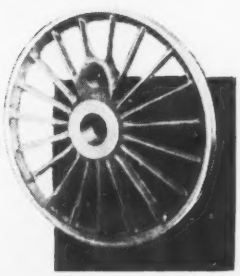


Few machines have to be made to such rigid standards of strength and soundness as railway rolling stock. It is because of the need for calculated, unfailing strength in the component parts that Lloyds, with their unsurpassed facilities for scrupulous control at every stage of production, are called upon by Britain's leading locomotive and railway engineers to supply steel castings for their products. Castings made by Lloyds for the Railway industry include wheel centres (bottom right), loco frame cradles (above), bogie bolsters and axle boxes. *Send for a copy of Lloyds Craftsmen in Steel. Post free.*



Cast and machined by

LLOYDS



Britain's Best Equipped Steel Foundry

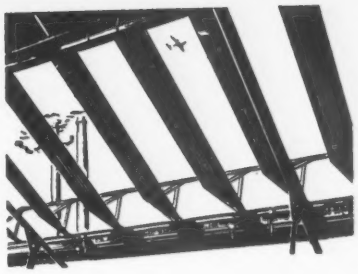
F. H. LLOYD & CO. LTD., P.O. BOX 5 · JAMES BRIDGE STEEL WORKS · WEDNESBURY · STAFFS · PHONE: DARLASTON 225

A Print for Industry Ltd. Advertisement

STRUCTURAL STEELWORK
BY
SOUTH DURHAM
for speed, efficiency, economy

SOUTH DURHAM STEEL & IRON CO. LTD.
(incorporating CARGO FLEET IRON CO. LTD.)
Central Constructional Department, Malleable Works,
STOCKTON-ON-TEES. *Telephone: 66117.*

Where industrial processes cause excessive fumes, smoke, steam, and heat, adequate ventilation can easily be provided by installing Hills Patent Roof Ventilating Shutters. These Shutters undoubtedly offer the simplest, most efficient and economical system of workshop ventilation, equally suitable for new or existing buildings. Touch a button, and the shutters will open up to an angle of 65 degrees in 60 seconds. Fresh air *rapidly* replaces stagnant air and smoke. Work goes on without a break—every hour of a worker's time can be made profitable. The Shutters will save their cost in a few months, and will last a lifetime. A postcard to our Technical Advisory Department will bring you full particulars by return.



★ **HILLS INDUSTRIAL VENTILATORS** *include power-operated Roof Ventilating Shutters, Stack Roof Ventilators for fitting with patent glazing bars or corrugated roof sheets, and Wall-type Air Inlet Ventilators for fixing into an opening 8ft. wide by 6ft.*

CLEAR THE AIR WITH

HILLS roof ventilating shutters

HILLS (West Bromwich) LTD., ALBION ROAD, WEST BROMWICH, STAFFS. Tel: WESt Bromwich 1025 (7 lines)

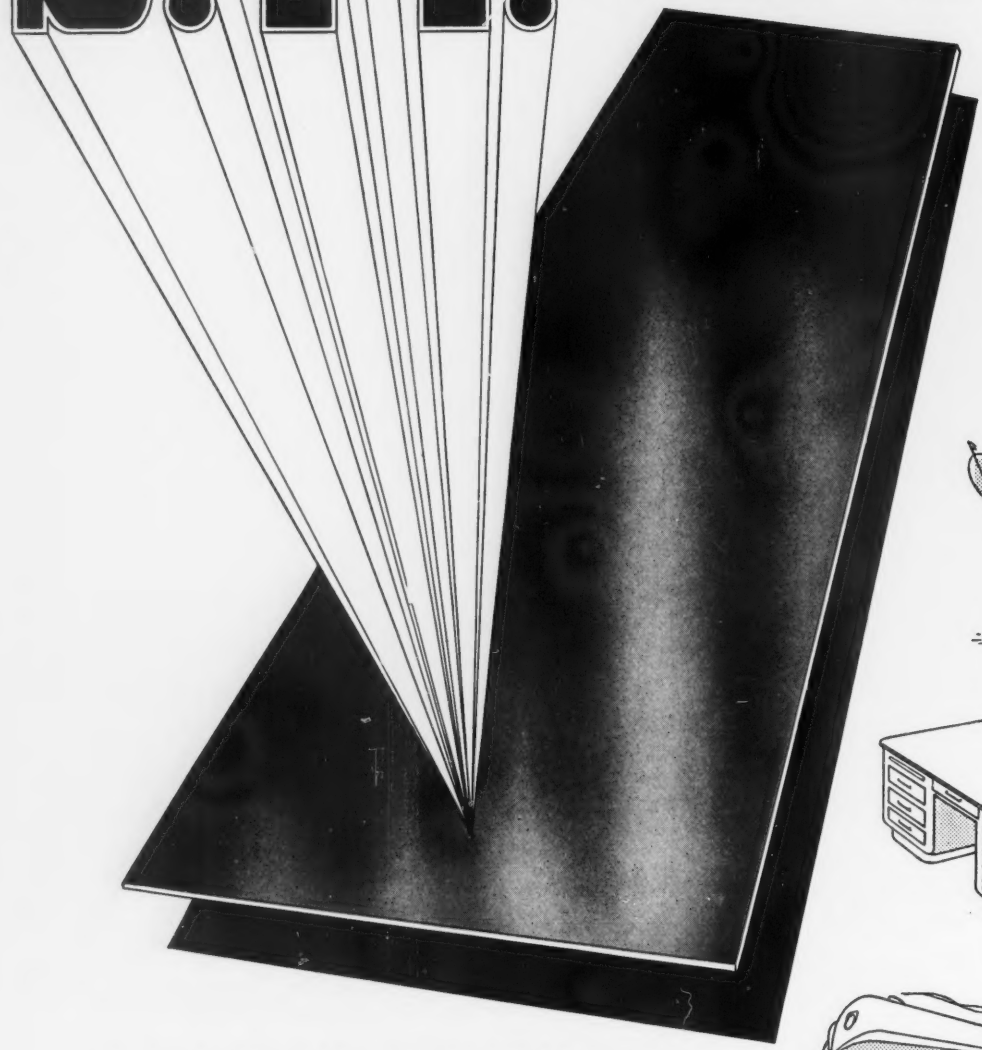
London: Chapone Place, 22, Dean St., London, W.1. Tel: GERrard 0526-9. Branches at Birmingham, Bristol, Leeds, Manchester, Newcastle-on-Tyne, Glasgow & Belfast.

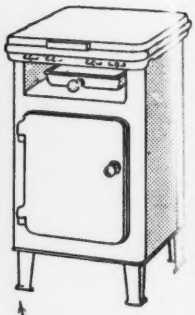
S. & M.

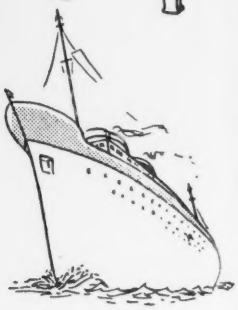
STEEL SHEETS

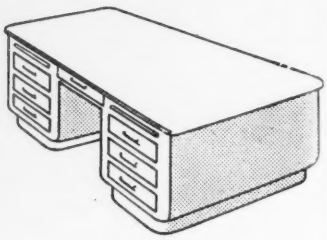
BLACK & GALVANIZED

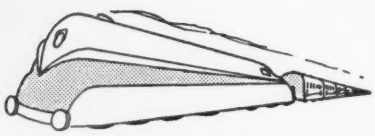
FOR ALL PURPOSES











We make the widest Sheets and have the largest galvanizing baths in Britain

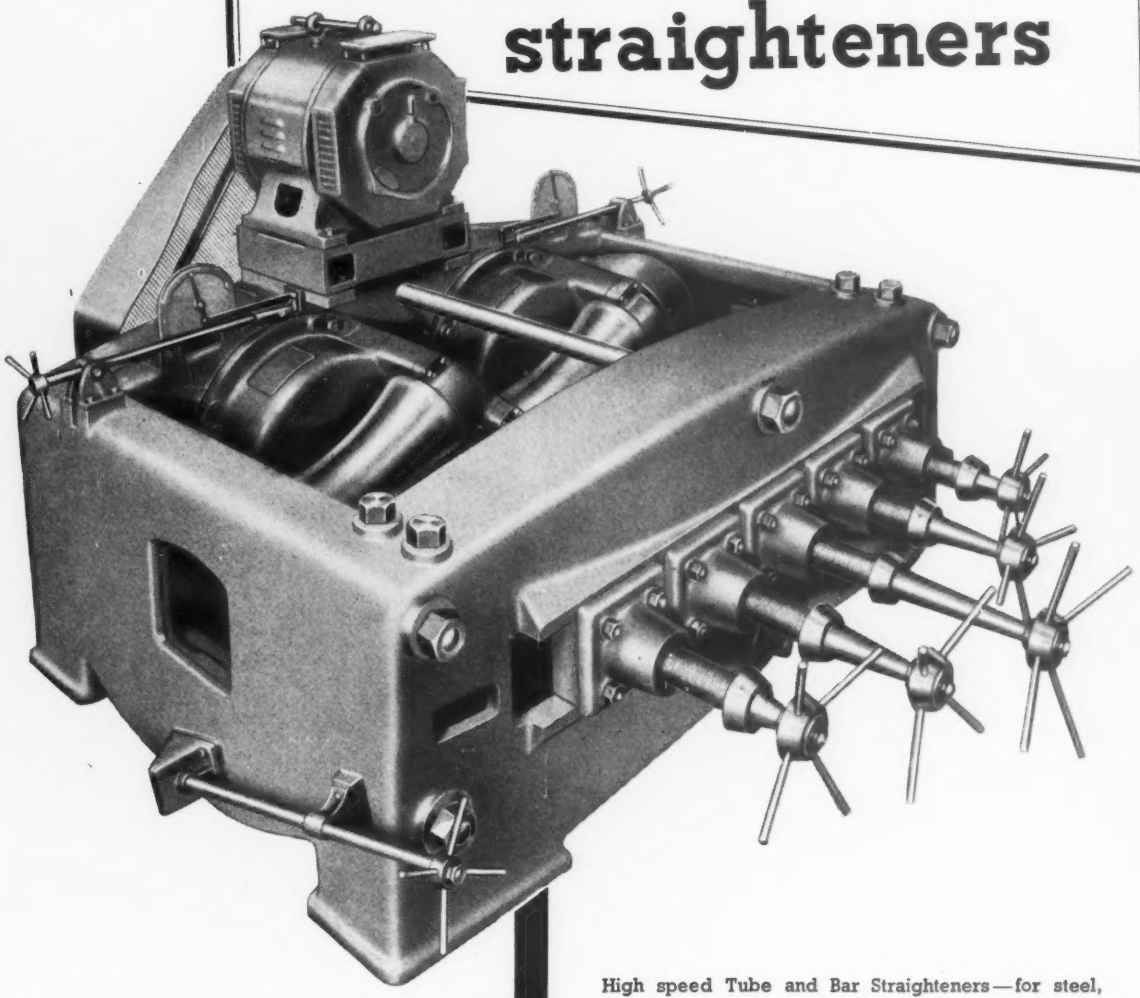
Smith & McLean, Ltd.

179 WEST GEORGE STREET, GLASGOW, C. 2.

Telephone: CENtral 0442

Telegrams: 'CIVILITY' Glasgow

High-speed tube and bar straighteners



High speed Tube and Bar Straighteners—for steel, copper, brass and aluminium tube and bar, with a fixed angle or adjustable angle, driving Rolls and three or five Idle Rolls. Machines available in 6 sizes for bar from ¼″ dia. to 9″ dia. mild steel, and ⅜″ dia. to 18″ dia. tube.

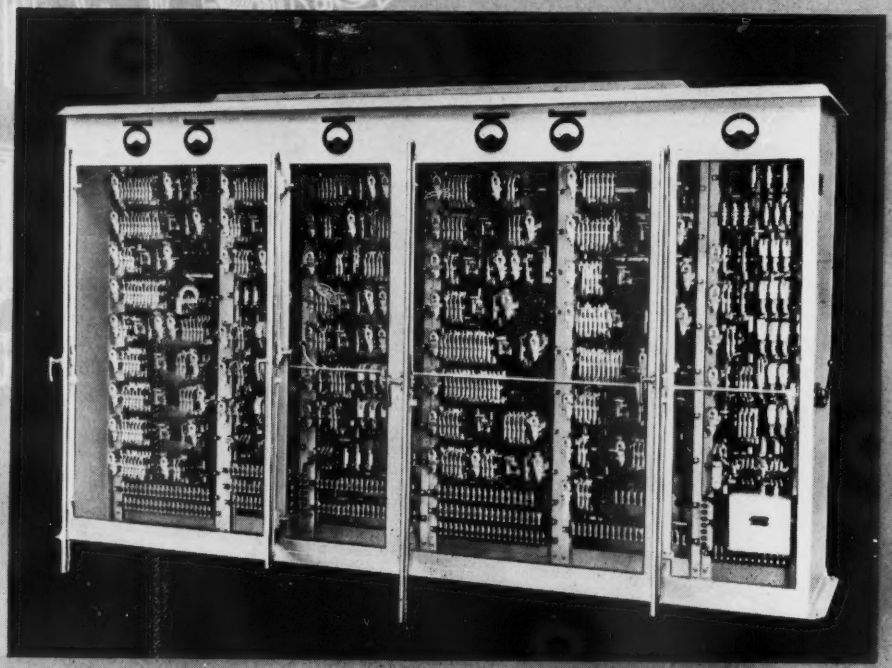
BIGWOOD

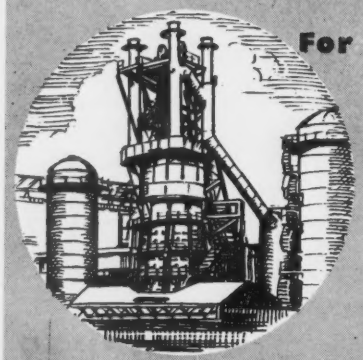
JOSHUA BIGWOOD & SON LTD · WOLVERHAMPTON · ENGLAND

B123

CONTACTOR SWITCHGEAR LTD
WOLVERHAMPTON
ENGLAND

Automatic Multi Motor Control Panels





For the Iron and Steel Industry

The ease of application of CONTACTOR SWITCHGEAR LTD. equipment to special schemes is typified by this illustration of a multi motor panel designed for control of a Rotary Hearth Furnace powered by various motors ranging up to 20 H.P.
All four doors are mechanically interlocked with the main isolator and operation of this equipment is obtained from a control desk also supplied by CONTACTOR SWITCHGEAR LTD.

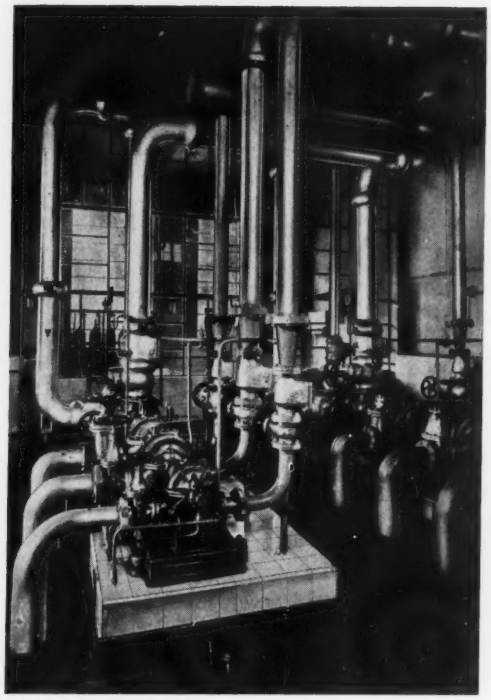
May we have your enquiries for automatic control gear?

CONTACTOR SWITCHGEAR LTD
BLAKENHALL WOLVERHAMPTON ENGLAND
Telephone: Wolverhampton 25111 (5 lines) *Telegrams:* TACTORGEAR Wolverhampton

INDUSTRIAL PIPEWORK

Complete Installation Service
for
STEEL WORKS, CHEMICAL WORKS, OIL REFINERIES, GENERATING STATIONS, TIN PLATE WORKS, GAS WORKS, etc., etc.

Steam · Water . Compressed Air · Pressure Lubrication · Hydraulic Systems · Petrol · High Pressure Gas · Heating · Acids and Chemicals, etc.
Gas and Water Main-laying



Current Contracts include:

STEEL COMPANY OF WALES, ABBEY, MARGAM, TROSTRE, & VELINDRE WORKS.
METAL BOX COMPANY, NEATH
ATOMIC RESEARCH STATION, HARWELL.
J. SUMMERS & SONS, LTD., STEEL WORKS, SHOTTON
LLANELLY STEEL CO., LTD.
DORMAN LONG & CO., LTD.
ROUND OAK STEEL WORKS.
REGENT OIL COMPANY (CANVEY ISLAND).
MONSANTO CHEMICALS LTD.
BRITISH INDUSTRIAL SOLVENTS LTD.
CHEMICAL ENGINEERING (WILTONS) LTD.
ADMIRALTY etc.

WILLIAM PRESS & SON
LIMITED

22 QUEEN ANNE'S GATE, WESTMINSTER, S.W.1
Telephone: WHItehall 1752-3 & 2961 *Telegrams:* Unwater, Parl, London

WILLOUGHBY LANE, TOTTENHAM, N.17
Telephone: TOTtenham 3050 (12 lines) *Telegrams:* Unwater, Southtot, London

The Performance of the Two-Stage Gas Producer

The GI Two-Stage Gas Producer represents a very substantial advance in the technique of producing gas from coal. Both economically and technically the operation of this type of Gas Producer differs radically from any other.

A simple diagram, see Fig. 1, is enough to show how, basically, this type of Producer works. The design and the general arrangement of the Generator is the main factor in the plant's performance.

The GI Generator has two off-takes. One, the lower of the two, is located immediately above the zone in which gasification takes place. This lower off-take is so constructed that a proportion of the hot gas is passed upwards through the descending fuel charge to provide sensible heat in this distillation zone. The products of distillation and that part of the hot gas diverted from the lower off-take leave by the other off-take at the top of the Generator. In this way the temperature of the zone is kept below that at which partial cracking of the products would take place.

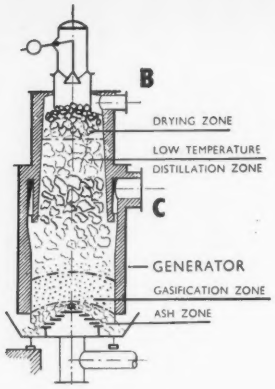


Fig. 1.

It may be difficult to conceive of a Gas Producer plant supplying **hot raw gas** for an indefinite period of years without shut-down, but that is the performance of a Two-Stage Pre-Distillation Gas Producer. In a booklet we have recently published, reference is made to a plant in Linz-am-Donau supplying hot raw gas which has already been in continuous operation for four years without it being necessary to burn out the insulated main, which is over 450 ft. long.

The thermal efficiency of a hot raw gas GI Two-Stage Producer, including gas, tar and sensible heat, is of the order of 0.90, and that of a plant supplying cold clean gas is, on the cold gas basis, about 0.75. The quality of the gas produced is very high and its gross calorific value may be over 175 B.T.U. per cubic foot.

A full description of the GI Two-Stage Gas Producer plant is contained in a booklet which we have recently published and all interested engineers should obtain a copy of this publication.

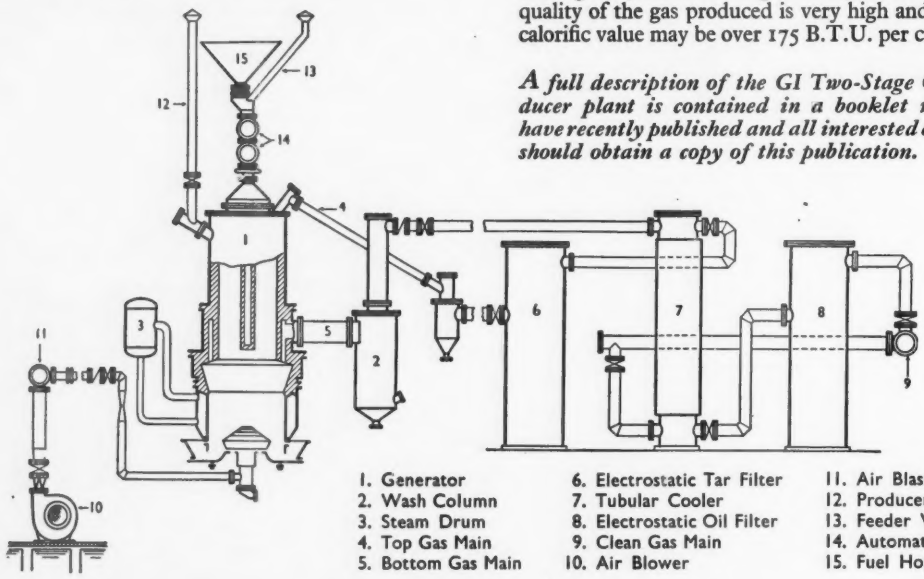


*Fig. 2. Diagram of a Two-Stage Pre-Distillation Producer Gas Plant with electrostatic tar and oil filters and other necessary plant for the production of **cold clean gas**.*

Please address enquiries to:

THE INTERNATIONAL FURNACE EQUIPMENT COMPANY LIMITED
ALDRIDGE STAFFS.

IFE

Combustion Engineers

STEPHENS'

Super Grade Low Alumina
Silica Brick

•

FINE SILICA CEMENT FOR SETTING SILICA BRICK

•

STIGNIC CEMENT FOR BASIC STEEL LADLES

KILN CAPACITY OVER 1½ MILLION BRICKS

•

SPECIAL FIRE CEMENTS for all purposes

•

STEPHENS' SPECIAL ELECTRIC FURNACE ROOF BRICKS

REGENN BRICK without doubt the best Brick for Soaking Pits, Checkers, and Regenerator Chamber Walls

•

Stephens SILICA BRICK CO., LTD.
KIDWELLY

Telegrams :—STEPHENS, KIDWELLY.
Telephone :—KIDWELLY No. 1

Codes :—ABC 4th & 5th Editions
Liebers & Marconi

VISCO
Reciprojet SELF-CLEANING
AIR FILTER

Thirty years' experience of Air Filtration problems and a considerable amount of experiment have combined to produce the new Visco "Reciprojet" Self-Cleaning Air Filter. This filter is designed for use in situations where the atmosphere has an exceptional dust load; as in Steelworks, Collieries, Cement Works, Quarries, etc. It is strongly recommended for use in the ventilation of electrical machinery.

Here are the main features of this, the finest air filter devised for very dusty locations :—

- **Simple, all-metal construction. Two stage filtration.**
- **Automatic operation; time switch control.**
- **Regular cleaning of each cell without removal of cells.**
- **Effectual draining of oil from cells. Positive prevention of oil carry-over.**

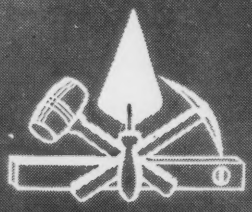
WRITE FOR DETAILS

Two sections of a Patent Automatic "Reciprojet" Air Filter forming part of a 12 section filter of 80,000 c.f.m. capacity supplied to a steelworks. View of dirty air side showing part of reciprocating mechanism.

Consult us on all Air Filtration Problems

Phones: CROydon 4181/4

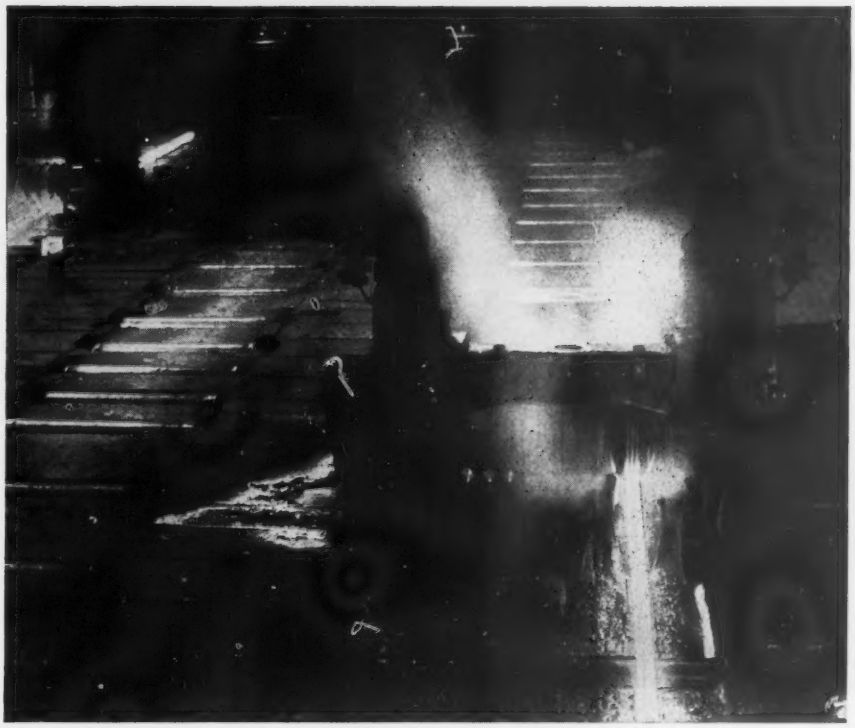
VISCO ENGINEERING CO. LTD. STAFFORD RD. CROYDON



SPECIALISTS
IN THE CONSTRUCTION OF
FIREBRICK LININGS
FOR
BLAST FURNACES HOT BLAST STOVES
AND
AUXILIARY PLANT. ALSO DEMOLITION OF EXISTING LININGS.

BOWDEN-JACKSON (CONSTRUCTIONS) LTD
24 BASINGHALL STREET, LEEDS 1
PHONES: 21670-9

Lancashire Steel



THE LANCASHIRE STEEL CORPORATION LIMITED

Telephone : **1600**

WARRINGTON

Telegrams : **LANCASTEEL**

Works : **IRLAM & WARRINGTON**

BASIC PIG IRON FERRO-MANGANESE
SIEMENS-MARTIN OPEN-HEARTH BASIC STEEL
ROLLED AND RE-ROLLED STEEL PRODUCTS

LONDON OFFICE : 17 NORTHUMBERLAND AVENUE, TRAFALGAR SQUARE, W.C.2 *Telephone :* WHITEHALL 7515 *Telegrams :* LANCASTEEL, RAND, LONDON

Associated Companies :
THE PEARSON & KNOWLES ENGINEERING CO. LTD. RYLANDS BROTHERS LTD. WHITECROSS COMPANY LTD

THE LANARKSHIRE STEEL Co. Ltd.

Structural Steelwork
Colliery Arches
Forging Blooms
Sections
Joists
Slabs

★ ★

Works and
Head Office :—
FLEMINGTON
MOTHERWELL

Phone: - Motherwell 347

THE IRON AND STEEL INSTITUTE, 4, GROSVENOR GARDENS, LONDON, S.W.1

SPECIAL REPORT No. 46
THE ALL-BASIC OPEN-HEARTH FURNACE

Amply illustrated with diagrams and photographs. Bound in cloth with stiff board covers

Price: Members 15s. Non-members 25s.

The latest addition to the series of Special Reports published by the Institute is a report on "*The All-Basic Open-Hearth Furnace*", prepared by a joint sub-committee of the British Ceramic Research Association and the British Iron and Steel Research Association. The papers were presented at the 36th Steelmaking Conference at Ashorne Hill in May, 1951, and a report of the discussion at the Conference is included.

The All-Basic Open-Hearth Sub-Committee was formed shortly after the war ended to promote research on and development of the all-basic furnace, and as a result of preliminary study, six furnaces of varying designs were constructed, five in Great Britain and one in Holland.

Very full details of the experiments made on these furnaces, together with the results, and observations of their performance, are presented in Part III in what is considered to be the most suitable form for study and comparison of results ; it is hoped that this will constitute in the future a standard method of recording information. The potentialities for further research and development are considered to be very great, and the Report suggests the lines along which future investigation should be carried out, if the all-basic furnace is to become an economic proposition. Great stress is laid on the need for the development of an improved and cheaper basic brick, and for better aerodynamic and mechanical design.

Copies may be obtained by application to the Secretary, The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1

CENTRALIZED LUBRICATION EQUIPMENT

by

TANWAY

NEW

Brochure now available Please ask for copy.

Efficient and positive lubrication is absolutely imperative in open and inevitably dusty operating conditions such as those obtaining with this Ore Stocking Bridge. Tanway GP Centralized Lubrication was fitted in the knowledge that it is efficient and positive and—it never misses a point.

TANWAY LTD., BARNBY DUN, DONCASTER, ENGLAND

TELEPHONE: BARNBY DUN 256

Exclusive Canadian Distributor: S. F. BOWSER COMPANY LTD., HAMILTON, ONTARIO.

LS

CONSTABLES FLUORITE

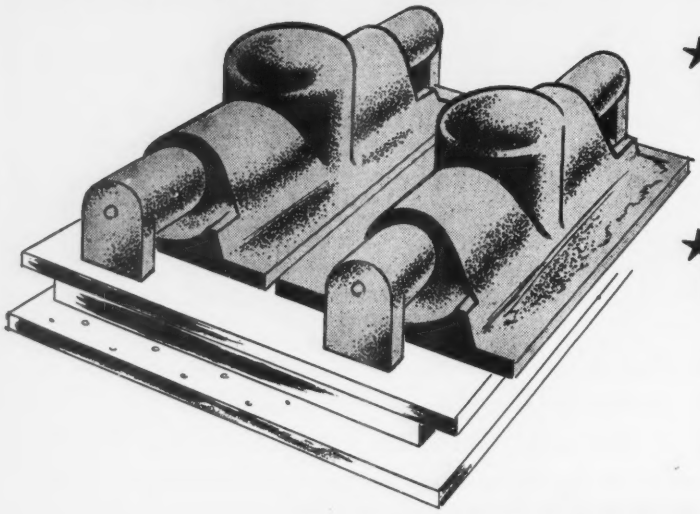
Fluorspar of high calcium fluoride and low silica content for all metallurgical purposes. Export enquiries welcomed. Guaranteed quality.

CONSTABLES (MATLOCK QUARRIES) **LTD**

Members of British Fluorspar Producers Association

BANK HOUSE, THE BRIDGE, MATLOCK, DERBYSHIRE TELEPHONE MATLOCK 741

'FULBOND' 2 in oil-bonded cores



★ **GREEN STRENGTH**

1% Fulbond 2 replaces 10% natural sand

★ **PERMEABILITY**

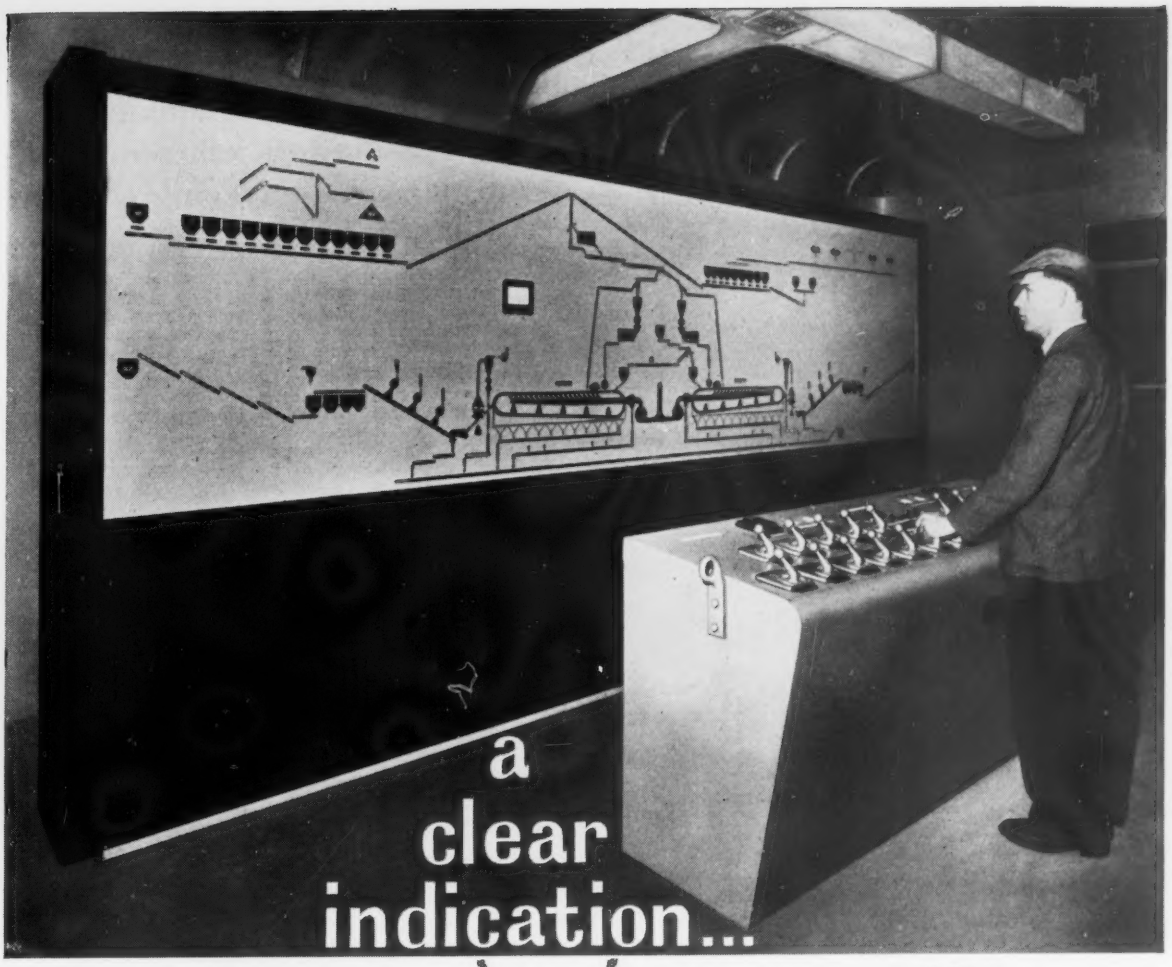
1% Fulbond 2 does not reduce permeability; the equivalent 10% natural sand does

For service and information write to:—

THE FULLERS' EARTH UNION LTD

Patteson Court, Redhill, Surrey. Tel: Redhill 3521

CMF 14



a clear indication...

A clear indication of the operating conditions of industrial plant enables the control engineer instantly . . . efficiently . . . economically to monitor his machinery, remotely from a central point.

Standard electrical indication diagrams, custom-built to meet any industrial requirement, open up new opportunities for increasing productivity and lowering plant operating costs.

The electrical indication diagram illustrated is part of a **Standard** *system at the Steel Company of Wales Margam, ore preparation plant. This installation has been successfully applied to the control of widely dispersed raw material handling and processing machinery used in the production of rubble iron ore, coke breeze and sinter.*

Standard indication diagrams

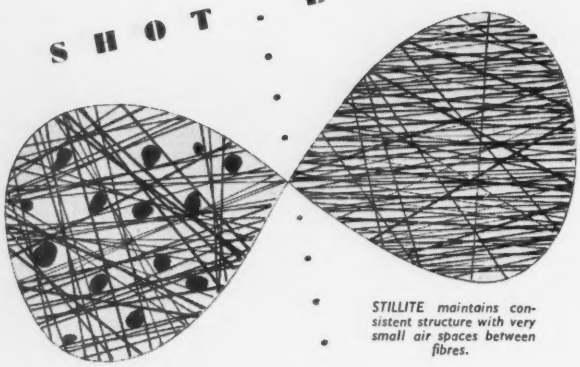
Ask *Standard* engineers to discuss electrical indication diagrams as applied to YOUR plant. Their advice and recommendations will be gladly and freely given.

Standard Telephones and Cables Limited

Registered Office: Connaught House, Aldwych, London, W.C.2

TELEPHONE DIVISION: OAKLEIGH ROAD, NEW SOUTHGATE, LONDON, N.11

SHOT ELIMINATION



"Shot" causes relatively large air spaces that allow passage of heat by convection.

STILLITE maintains consistent structure with very small air spaces between fibres.

—for maximum insulation efficiency and increased covering capacity

When lumps of solid matter are present in a fibrous insulating material its efficiency is inevitably impaired. Such lumps, technically known as "shot", add to the weight of the material, but are of no insulating value, as they do not prevent movement of the air trapped in the interstices between the fibres. And it is upon immobilised air that the insulating efficiency of the material depends.

All STILLITE insulants consist of finely divided mineral wool fibres consistently packed, with remarkable freedom from "shot" content—an ideal basic material. This material is then processed into a range of insulants of different densities and forms that cater for virtually every class of insulation against heat, cold and sound.

The STILLITE range of thermal insulants includes:

+ **Felted and Pelleted Mineral Wool for loose-fill insulation**
+ **Semi-rigid slabs in various densities to cover temperatures ranging from −400°F. to +1500°F.**
+ **"Stilag" pre-formed sections for pipe-work insulation**
+ **Quilts, Building Mat, Mattresses, Flexible Sections, Felted Strip, and Insulating Cement**

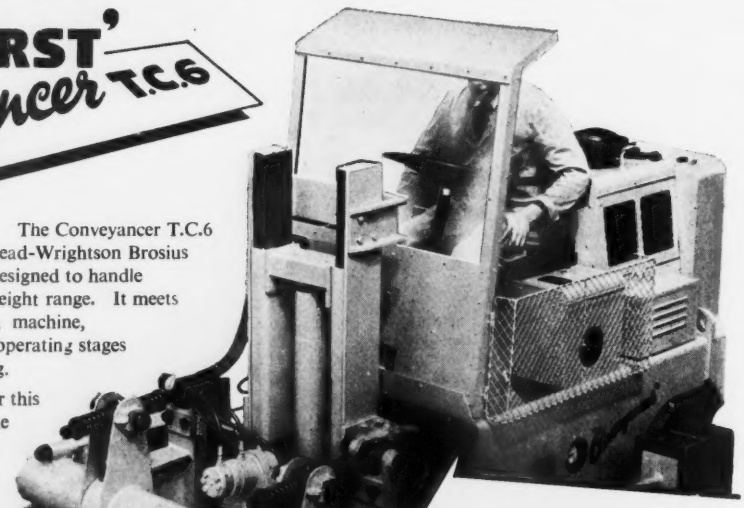
For general information write for Booklet J. "Insulation for Heat, Cold and Sound". Technical Data sheets on specific materials are also available.

STILLITE *provides an insulant for every purpose*

STILLITE PRODUCTS LIMITED, 15 WHITEHALL, LONDON, S.W.1. Tel.: WHitehall 0922/6. Grams.: Stillomite, Parl, London

ANOTHER 'FIRST'

THE Conveyancer T.C.6



The Conveyancer T.C.6 fitted with Head-Wrightson Brosius Manipulet is a mobile Manipulator designed to handle work pieces in the light-medium weight range. It meets the demand for a light weight, low-cost machine, capable of simplifying and uniting the operating stages involved in the process of forging.

Fluid Transmission is an essential feature for this type of work, and T.C.6 incorporates the renowned Turbo Hydraulic Torque Converter making it ideal for the close-limit operations necessary in this class of work.

For full information on the Manipulet and Conveyancer T.C.6. Write for leaflet.

fitted with HEAD-WRIGHTSON BROSIUS MANIPULET

Conveyancer

FORK TRUCKS LTD
WARRINGTON ENGLAND

Tel: WARRINGTON 2244

Member of the Owen Organisation

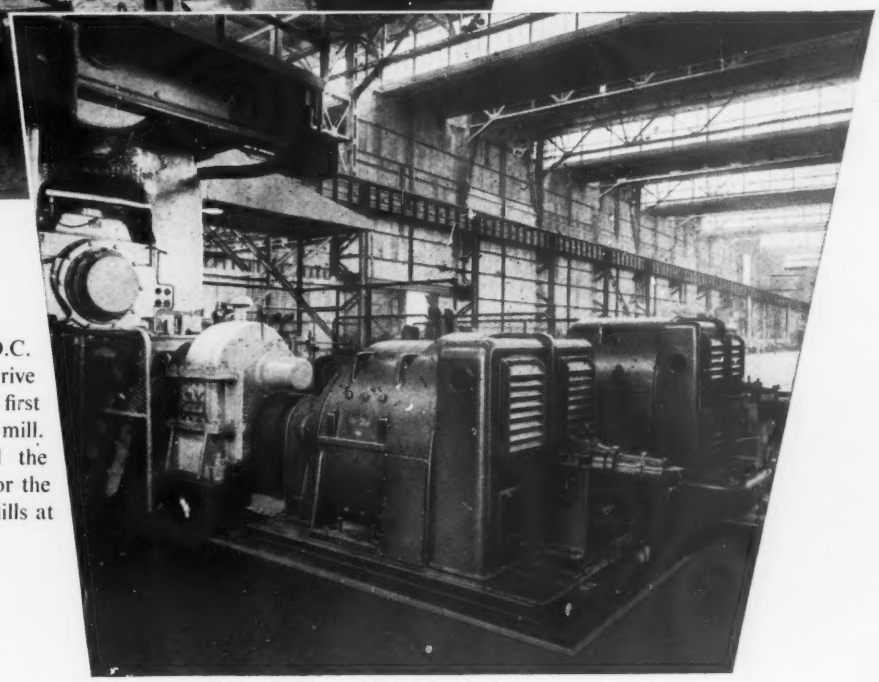
A879

G.E.C. EQUIPMENT

at THE STEEL COMPANY OF WALES LTD.

TROSTRE WORKS

The G.E.C. supplied the main electrical plant and control gear for the pickle line. The 97½ h.p. totally enclosed, fan-cooled D.C. motors driving the pinch rolls at the end of the tank section are illustrated.



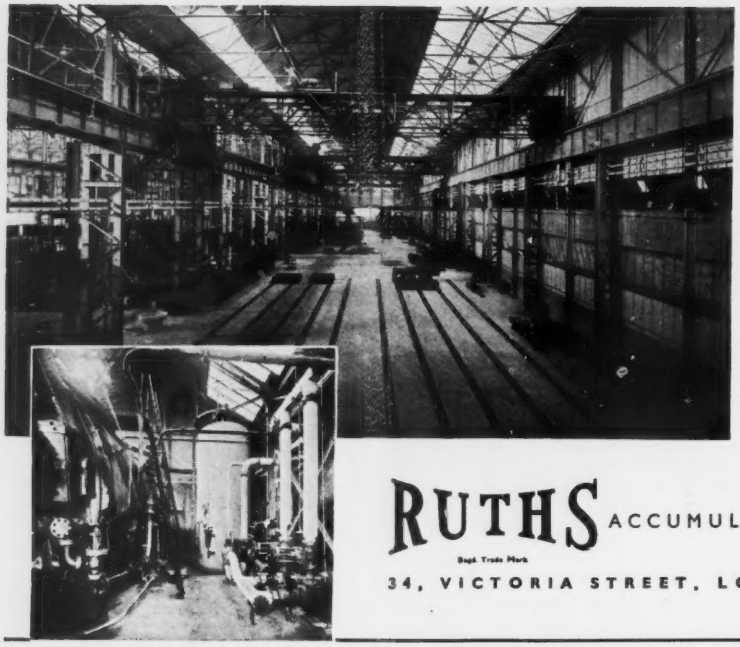
1000 h.p. and 500 h.p. D.C. motors for the main drive and tension rolls of the first stand of No. 1 temper mill. The G.E.C. built all the electrical equipment for the two 2-stand temper mills at the Trostre Works.

Consulting Engineers: McLellan & Partners.

THE GENERAL ELECTRIC CO. LTD · MAGNET HOUSE · KINGSWAY · LONDON · W.C.2

HEATED WITH A RUTHS CASCADE HEATER

Regd. Trade Mark



High pressure hot water heating system at Vickers-Armstrongs Ltd., Barrow-in-Furness, by The Brightside Foundry & Engineering Co. Ltd.

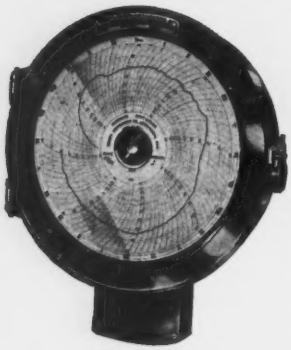
This shop consists of 3 bays, each 470′ long, 70′ wide and 45′ high to the eaves. It is heated by 143 "Brightrad" panels supplied with water at 200 lbs. sq./in. and providing a mean surface temperature of 280°F. The water comes from a 18′ x 6′ dia. Ruths Cascade Heater (flow temp. 385°F., return 325°F.) shown on the right of the small photograph, which converts steam from the Cochran Economic Boiler on the left.

RUTHS ACCUMULATORS (COCHRAN) LTD

Regd. Trade Mark

34, VICTORIA STREET, LONDON, S.W.1

TAS/CH.544

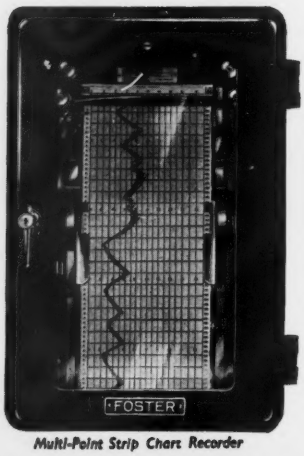


Dial Recorder

FOSTER

PYROMETERS

For over 40 years we have specialised in the design, production and application of pyrometers. This experience has enabled us to produce a range of instruments to satisfy the needs of practically every modern industrial process. Your problem in pyrometry is our problem and, having solved it, we ensure that the instruments supplied continue to give satisfactory and reliable service.

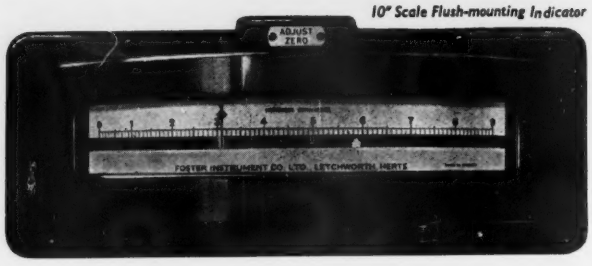


Multi-Point Strip Chart Recorder

5" Scale Circular Wall Type Indicator

★ We also make the FOSTER INTROSCOPE for internal inspection of inaccessible parts, including pipe welds, diesel jets, etc.

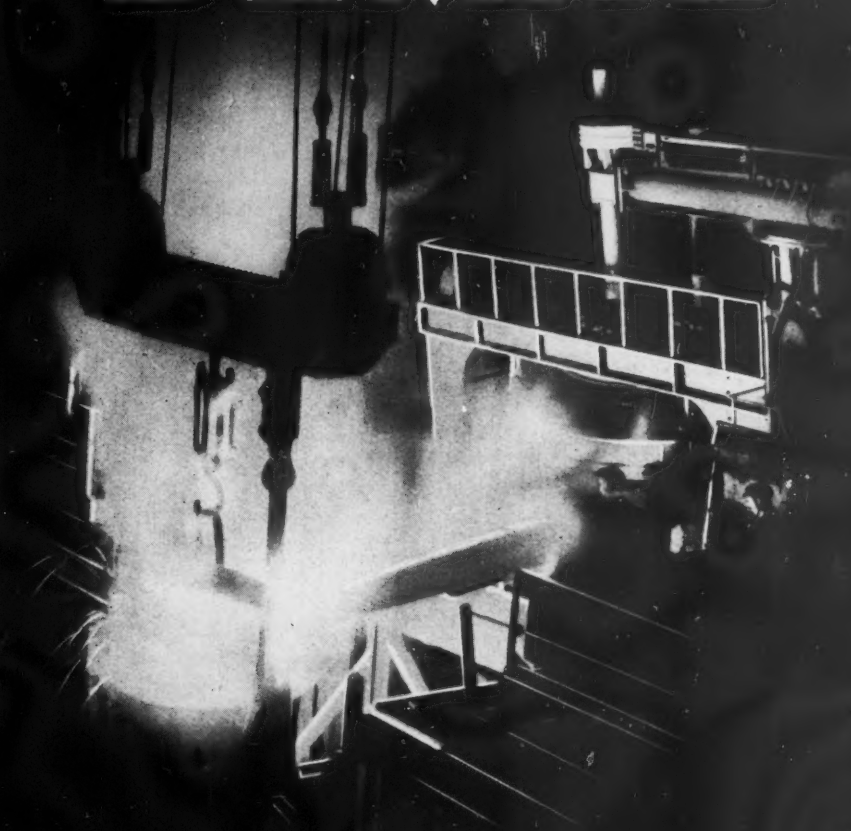
10" Scale Flush-mounting Indicator



FOSTER INSTRUMENT CO., LTD., LETCHWORTH, HERTS.

Telephone: LETCHWORTH 984 (3 lines) ENGLAND Telegrams: RESILIA, LETCHWORTH

DEMAG



ARC FURNACES
For Foundries and Steelworks

SMOTHERED ARC FURNACES
For Carbide, Pig-Iron, Ferro-Alloys
Corundum and the Reduction of Ores

HIGH AND LOW FREQUENCY MELTING FURNACES
For Special Steels, High Duty Alloys,
Copper, Aluminium, Zinc and Cast Iron.
Electrolytic Plant for the Production,
Refining and Recovery of Base and Precious Metals.

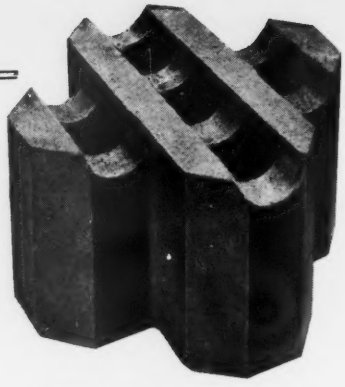
DEMAG-ELEKTROMETALLURGIE G.M.B.H.
KARLSRUHE DUISBURG W. GERMANY

REPRESENTATIVES FOR THE UNITED KINGDOM
D.M.M. (MACHINERY) LTD.
66, VICTORIA STREET LONDON S.W.1 Tel: VIC 6565

(By courtesy of Messrs. Ashmore, Benson, Pease & Co.)

FROM THE 'AXE' RANGE OF REFRACTORIES

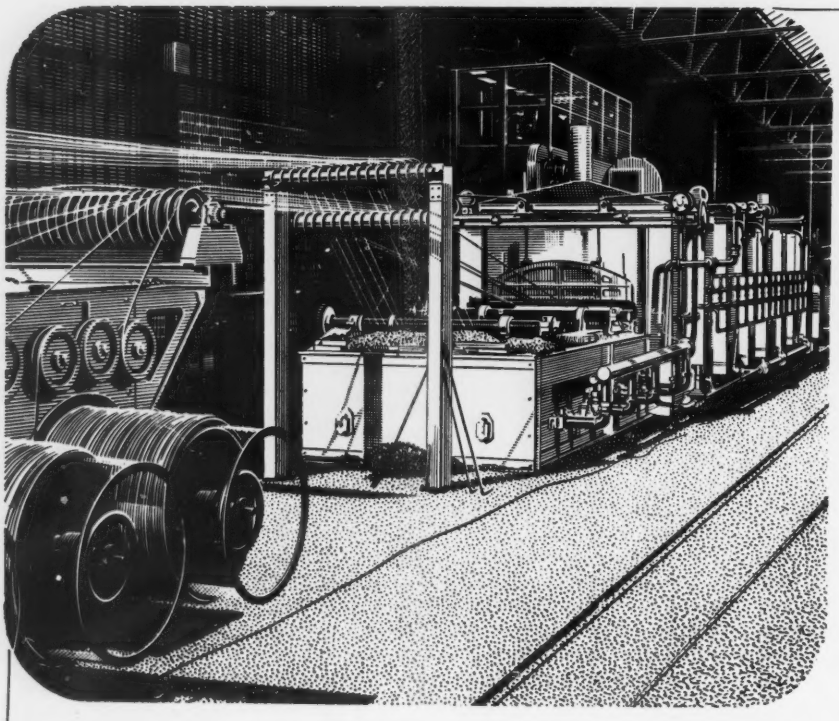
Freyn and McKee checkers supplied by THE BURN FIRECLAY CO. LTD., for the most modern installations in leading Iron and Steel Works.



(By courtesy of Messrs. Head, Wrightson & Co. Ltd.)

THE BURN FIRECLAY CO., LTD.
76 JESMOND RD. NEWCASTLE-ON-TYNE 2
Manufacturers of
THE 'AXE' RANGE
OF REFRACTORIES

Write for particulars and technical data



HEAT TREATMENT BY GAS

Town's Gas-fired continuous wire patenting furnace, open type, without muffle or tubes

We have over 50 similar furnaces in operation

- **HIGH PRODUCTION**
- **MINIMUM SCALE LOSS**
- **UNIFORMITY IN WIRE**
- **SIMPLICITY IN CONTROL**
- **LOW UPKEEP**

BRITISH FURNACES LTD · CHESTERFIELD

Associated with Surface Combustion Corporation, Toledo, U.S.A.

ECONOMY, COVERAGE, DURABILITY

makes

MIRACULUM

RED LEAD FILLER

OBVIOUS CHOICE FOR LASTING STEEL PROTECTION

Miraculum is every bit as efficient as genuine red lead, plus these important advantages. It covers twice the area, cutting material costs. Miraculum works so easily and smoothly labour costs are saved. It is regularly first choice as the essential protective priming coat and perfect second coat key for steel structures all over the world. Structural Engineers *know* that whichever way they look at it—with Miraculum they can't go wrong.

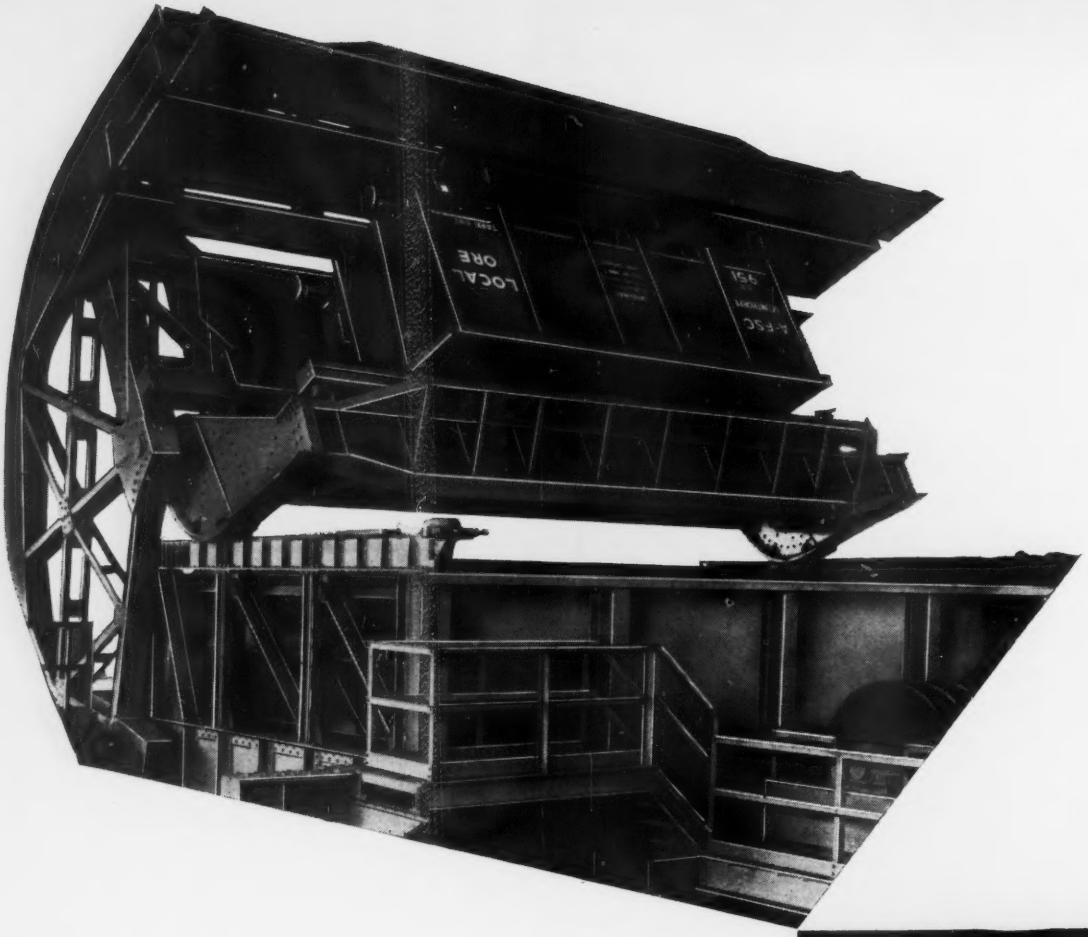
Steel Protection is our Business

BRITISH PAINTS LIMITED

PORTLAND ROAD, NEWCASTLE UPON TYNE, 2. Tel: 25151.

CREWE HOUSE, CURZON STREET, LONDON, W.1. Tel: GROSVENOR 6401-5.

BPL/BM9



Incoming ore at the Seraphim project of the Appleby-Frodingham Steel Company is handled by a

FRASER & CHALMERS
WAGON TIPPLER

Fraser & Chalmers were also responsible for building and erecting the complete interconnecting conveyor equipment at Seraphim, as well as sinter plant conveyor units, hammer mills, screens and feeders.

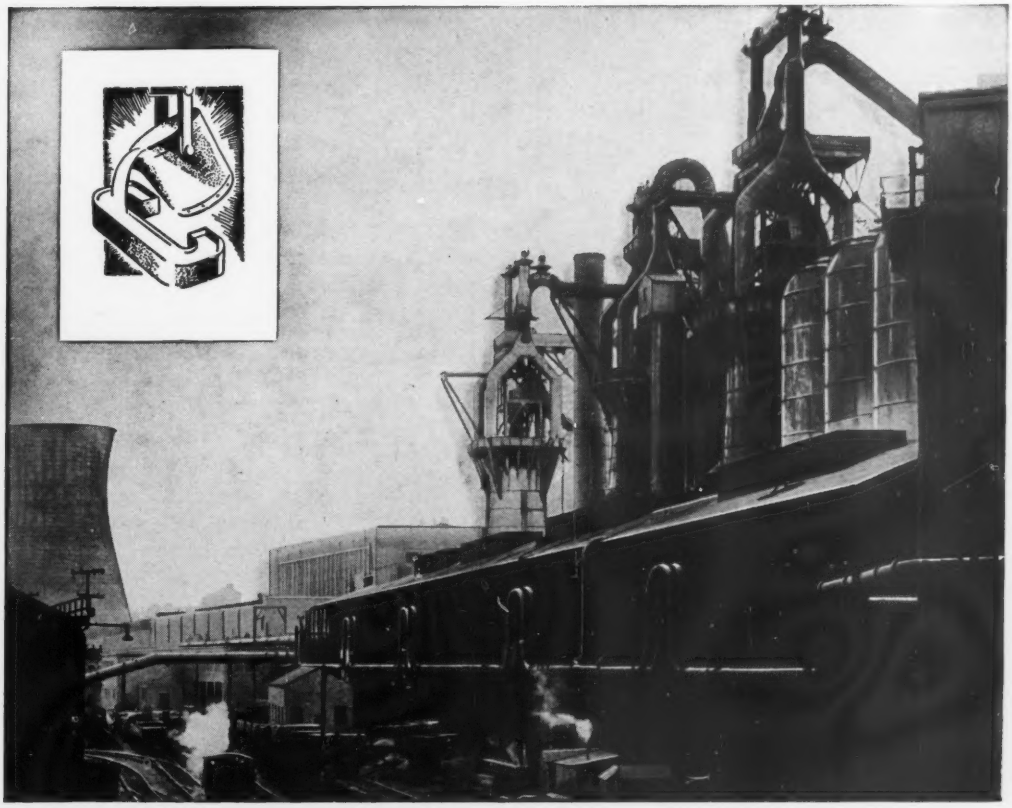
FRASER & CHALMERS

FRASER & CHALMERS ENGINEERING WORKS
ERITH · KENT

THE GENERAL ELECTRIC CO. LTD., OF ENGLAND
FC79

CONSETT

BASIC PIG IRON · PLAIN PLATES · FLOOR PLATES · · · ADMIRALTY DIAMOND · · · 'SUPERTREAD' & 'SUPERGRIP' · · NICKEL & MONEL CLAD PLATES · LIGHT SECTIONS AND HOT ROLLED STRIP · BLOOMS, BILLETS & SLABS · · · · SPECIAL STEELS · · · REFRACTORIES · ·



CONSETT IRON CO.
LIMITED
CONSETT · CO. DURHAM · ENGLAND

TELEPHONES: CONSETT 341 (12 LINES). TELEGRAMS: STEEL, PHONE, CONSETT

BAIRDS & SCOTTISH STEEL
LIMITED

STEEL
OPEN HEARTH PROCESS
Blooms, Slabs, Billets and Sheet Bars ; Light Rails and Rolling Stock Sections ; Bars, Hoops and Strips, Reeled Bars ; Splayed Coopers and Baling Hoops.

●

WROUGHT IRON
Bars, Angles, Tees, Channels, etc.
Horse Shoeing Bars, Tyre Bars.

●

PIG IRON
FOUNDRY · FORGE · HEMATITE
and BASIC
"GARTSHERRIE" and "EGLINTON" Brands

●

COKE NUTS
Industrial and Domestic

LIME and LIMESTONE
Agricultural and Industrial

CEMENT

BAIRDS & SCOTTISH STEEL LTD.

Pig Iron, Coke, Lime, Limestone, Cement
168 W. GEORGE ST., GLASGOW, C.2.

Telegrams : "SCOTOIRON Glasgow"

Wrought Iron and Steel
53 BOTHWELL ST., GLASGOW, C.2.

Index to Advertisers

Adamson-Alliance Co., Ltd. ... 17
Adamson, Joseph and Co., Ltd. —
Armstrong Whitworth, (Metal Industries), Ltd. ... ... —
Arrol, Sir Wm., & Co., Ltd. —
Ashmore, Benson, Pease & Co., Ltd. Inside Back Cover
Avery, W. & T., Ltd. ... 1

Bairds & Scottish Steel, Ltd... 82
Beardmore, William, & Co., Ltd. ... ... —
Bigwood, Joshua, & Son, Ltd. 63
Birlec, Ltd. 25
Blaw-Knox, Ltd. ... ... —
Bowden-Jackson (Constructions) Ltd.... 68
Bradley & Foster, Ltd. ... —
Brightside Foundry & Engineering Co., Ltd., The ... 18
British Continental Traders Ltd. 53
British Electrical Development Association 12
British Electro Metallurgical Co., Ltd. 8
British Furnaces, Ltd. ... 78
British Oxygen Co., Ltd. 42, 43
British Paints, Ltd. 79
British Rollmakers Corporation, Ltd. 24
British Thomson-Houston Co., Ltd., The 52
British Timken, Ltd.... ... 47
Brown Bayley Steels, Ltd. ... 2
Burn Fireclay Co. Ltd., The 78
Bushing Co., Ltd., The ... —

Chesterfield Tube Co., Ltd., The ... ... —
Climax Molybdenum Company of Europe, Ltd., The —
Cochran & Co., Annan, Ltd. —
Cohen, George, Sons and Co., Ltd. ... ... —
Colvilles, Ltd. 35
Consett Iron Co., Ltd. ... 81
Constables, Matlock Quarries) Ltd. 72
Contactor Switchgear, Ltd.... 64
Conveyancer Fork Trucks Ltd. 74
Coppee Co. (Gt. Britain) Ltd. 32
Crossley Bros., Ltd. ... ... —

Darwins, Ltd. ... ... —
Davy & United Engineering Co., Ltd. 58
Dewhurst & Partner, Ltd. ... —
D.M.M. Machinery, Ltd. ... 77
Doncaster, Daniel & Sons, Ltd. ... ... —
Dyson, J. & J., Ltd. 31

Electric Furnace Co., Ltd. ... —
Electric Resistance Furnace Co., Ltd. ... ... —
Electroflo Meters Co., Ltd. —
Elliott Brothers (London) Ltd. —
English Electric Co., Ltd., The 37
English Steel Corporation, Ltd. ... ... —
Evershed & Vignoles, Ltd. ... —
Excel Sound Service Ltd. ... —

Farmer-Norton, Sir James, & Co., Ltd. ... ... —
Ferodo, Ltd. 29
Inside Front Cover
Foster, Henry, & Co., Ltd. ... —
Foster Instrument Co. Ltd. ... 76
Fraser & Chalmers 80
Fullers Earth Union Ltd. ... 72

General Electric Co., Ltd., The 44, 75
General Refractories, Ltd. ... —
Gibbons Brothers, Ltd. ... 15
Glenboig Union Fire Clay Co., Ltd. ... ... —
Guest Keen Iron & Steel Co., Ltd. 4
Guest, Keen & Nettlefolds, Ltd. ... ... —
G.W.B. Electric Furnaces, Ltd. ... ... —

Hackbridge & Hewittic Co. Ltd. ... ... —
Hadfields, Ltd. ... ... —
Hallamshire Steel & File Co., Ltd., The ... ... —
Harland Engineering Co., Ltd. —
Head, Wrightson & Co., Ltd. —
Head, Wrightson Machine Co., Ltd. 34
High Speed Steel Alloys Ltd. —
Hills (West Bromwich) Ltd. 61
Honeywell-Brown, Ltd. ... 49

Igranic Electric Co., Ltd. ... 23
Ilford, Limited 22
International Construction Co., Ltd., The ... 38, 39
International Furnace Equipment Co., Ltd. 66
Jarrow Metal Industries Ltd. —
Jones Cranes ... ... —

Kelvin & Hughes (Industrial) Ltd. ... ... —
Kent, George, Ltd. ... ... —
Kestner Evaporator & Engineering Co., Ltd. ... 6
King, George W. Ltd. ... —
Kingscliffe Insulating Products, Ltd. ... ... —

Lafarge Aluminous Cement Co., Ltd. 27
Lamberton & Co., Ltd. Outside Back Cover
Lanarkshire Steel Co., Ltd., The 70
Lancashire Steel Corporation, Ltd., The 69
Lloyd, F. H., & Co., Ltd. ... 59
Lloyds (Burton) Ltd. ... —
Lodge-Cottrell, Ltd.... ... 33

Marshall, Thomas, & Co., (Loxley), Ltd. 40
Metropolitan Vickers Electrical Co. Ltd. ... ... —
Minworth Metals Ltd. ... —
Mitchell Engineering Ltd. ... 28
Mond Nickel Co., Ltd. ... 14
Moorwood, John M., Ltd. 20, 21
Morgan Crucible Co., Ltd., The 7, 46
Moxey Conveyor & Transporter Co. Ltd. ... ... —

Newalls Insulation Co., Ltd. ... —
Newell, Ernest & Co., Ltd. 3
Newton, Chambers & Co., Ltd. ... ... —
Nitralloy, Ltd. ... ... —

Oughtibridge Silica Firebrick Co. 9

Park Gate Iron & Steel Co., Ltd. —
Partridge Jones and John Paton, Ltd. ... ... —
Pickford Holland & Co., Ltd. 16
Pitman, Sir Isaac, & Sons Ltd. —
Popes Electric Lamp Co. Ltd. —
Powell Duffryn-Coppee Ltd. 19
Press, Wm., & Son, Ltd. ... 65
Priest Furnaces, Ltd. ... 50

Record Electrical Co. Ltd., The —
Robertson, W. H. A., & Co., Ltd. 45
Ross Engineers Ltd. 41
R.T.S.C. Home Sales Ltd. ... —
Ruths Accumulators (Cochran), Ltd. ... ... —

Salem Engineering Co., Ltd.... —
Shell-Mex & B.P., Ltd. ... 26
Sheppard & Sons, Ltd. ... —
Simon-Carves, Ltd. 51
Smith & McLean, Ltd. ... 62
Solus-Schall, Ltd. ... ... —
South Durham Steel & Iron Co., Ltd. 60
Standard Telephone & Cables Ltd. 73
Stanton Ironworks Co., Ltd., The ... ... —
Steel Company of Scotland, Ltd., The ... ... —
Stein & Atkinson, Ltd. ... —
Stein, John G., & Co., Ltd. ... —
Stephens Silica Brick Co., Ltd. 67
Stewarts & Lloyds, Ltd. ... —
Stillite Products, Ltd. ... 74
Summerson, Thos., & Sons, Ltd. 13
Super Oil Seals and Gaskets, Ltd. ... ... —

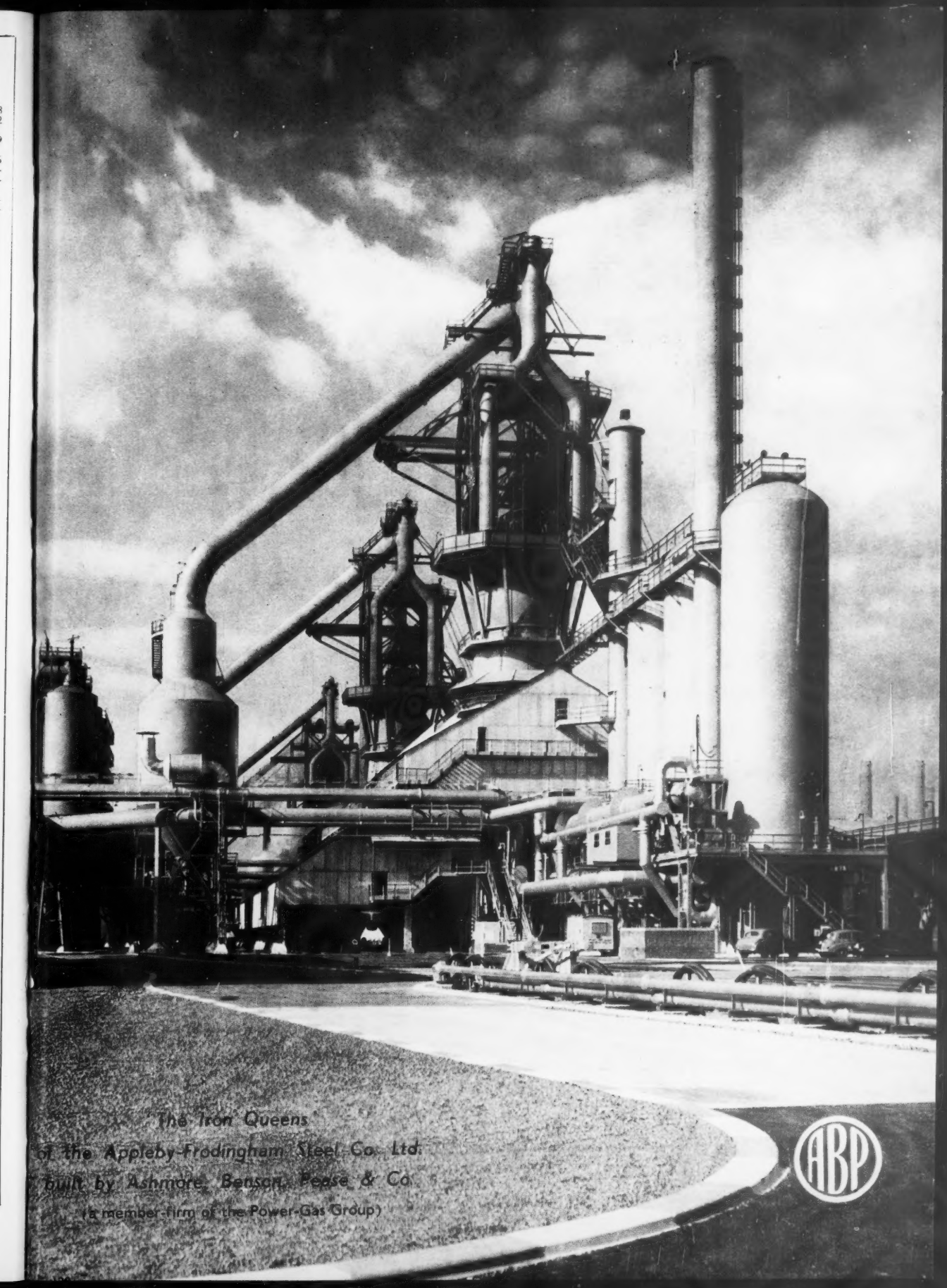
Tanway, Ltd. 71
Thomas (Richard) & Baldwins, Ltd. 55
Thornton, B., Ltd. 48

United Steel Companies, Ltd., The 56

Vacuum Oil Co., Ltd.... ... —
Visco Engineering Co., Ltd. 68

Wallsend Slipway and Engineering Co. Ltd. 17
Ward, Thos., W., Ltd. ... 11
Wellman Smith Owen Engineering Corporation Ltd., The 1
West Hunwick Silica & Firebrick Co., Ltd. 10
Whitehead Iron & Steel Co., Ltd. 30
Wiggin, Henry, & Co., Ltd. —
Wincott, G. P., Ltd.... ... 36
Woodall-Duckham Construction Co. Ltd. 5

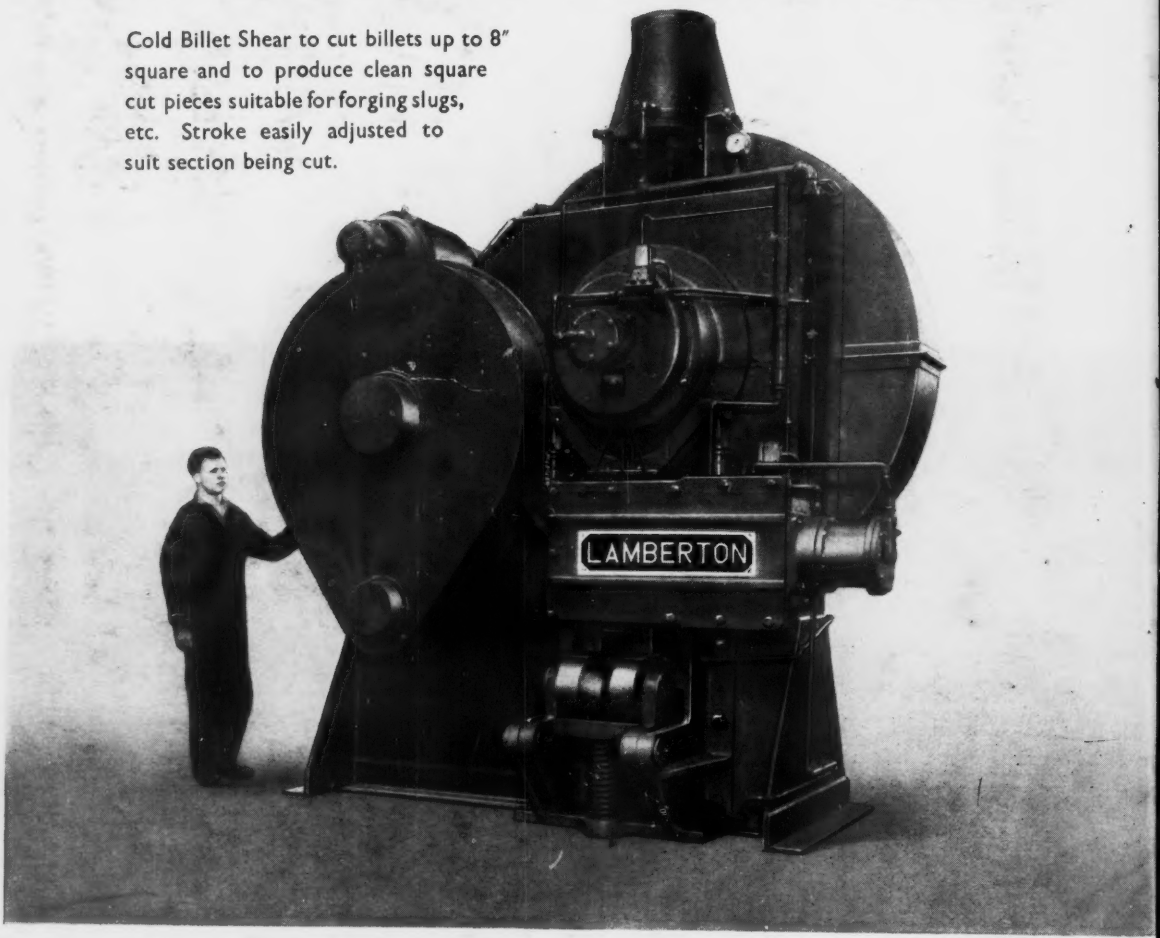
Published at the offices of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, and Printed in Great Britain by Harrison & Sons Ltd., Printers to the late King George VI, London, Hayes (Middx.) and High Wycombe.


The Iron Queens
of the Appleby-Frodingham Steel Co. Ltd.
built by Ashmore, Benson, Pease & Co.
(a member-firm of the Power-Gas Group)
ABP

now

a VARIABLE STROKE SHEAR

Cold Billet Shear to cut billets up to 8″ square and to produce clean square cut pieces suitable for forging slugs, etc. Stroke easily adjusted to suit section being cut.



LAMBERTON

STEEL WORKS PLANT

Makers also of cold shears for plates, bars and sheets as well as hot bloom and slab shears.

LAMBERTON & CO LTD
COATBRIDGE
SCOTLAND

#949929